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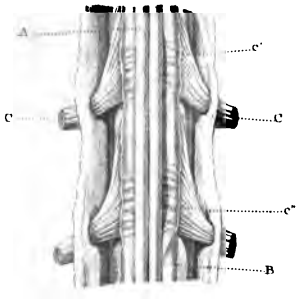

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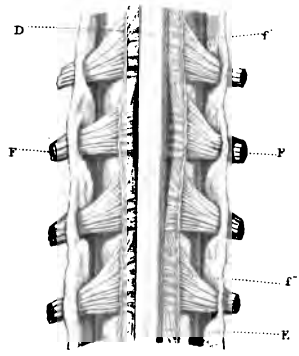

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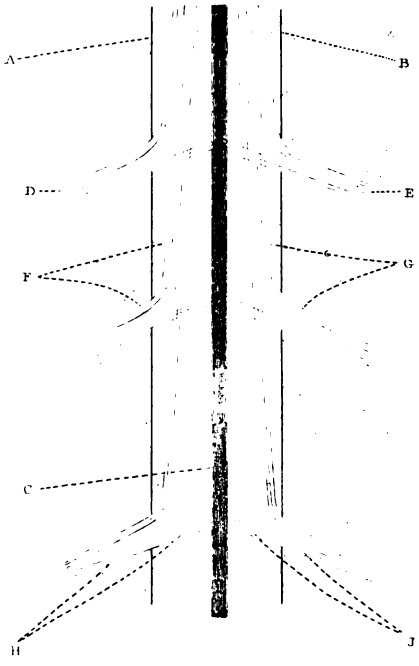

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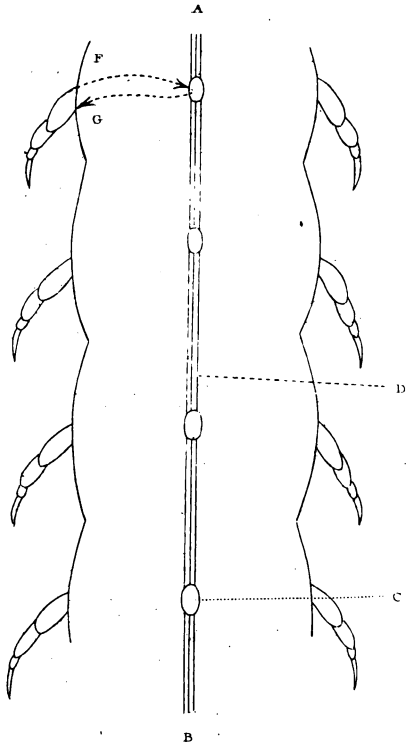

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OBSERVATIONS

ON THE

STRUCTURE AND FUNCTIONS

OF THE

SPINAL CORD.

BY

R. D. GRAINGER,

LECTURER ON ANATOMY AND PHYSIOLOGY.

"The first Almighty Cause
Acts not by partial, but by general laws."

LONDON:
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INTRODUCTION.

In the present treatise, an attempt is made to obtain some definite information, respecting a subject of the highest physiological import,—the true seat of sensation. A reference to the established doctrines is sufficient to convince every person whose judgment is not biassed by theories, as fallacious as they are universal, that our knowledge of the properties possessed by the nervous system, is not only inadequate satisfactorily to elucidate any one function of the animal economy; but is, in more than one respect, absolutely opposed to the dictates of common sense. In contemplating the operations of the inorganic world, nothing is perceived but harmony, regularity, and exactness; whilst, if we regard the phenomena of Nature, in the animal and vegetable kingdoms, as they are now interpreted, we discern only confusion and uncertainty.

The total insufficiency of the principles of physiology, as they are at present taught, is universally acknowledged; and a strong and daily increasing conviction has arisen, that the time is not far distant, when the scattered facts with which this science abounds, will be shown to depend on a few simple and general laws. The magnificent discoveries of comparative and developmental anatomy, by demonstrating the wonderful uniformity which prevails in the construction of animal bodies, plainly evince that such an anticipation is not visionary; for it would be an unparalleled anomaly in the laws of creation, if such unity of organization as is displayed, not only in the nervous, osseous, glandular, and other systems, but in the formation of the entire frame, were not accompanied by a corresponding simplicity in the laws which regulate the actions of this perfect machinery.

An extended and careful examination of the reflex power of the spinal cord, discovered by Dr. Marshal Hall and Professor Muller, has induced me to believe that it is only a part of a great principle, connected with the nervous system; from the application of which, in the investigation of all those motions which have

their source in contractility, the most valuable results may be anticipated, both in the animal and vegetable kingdoms. The laws by which this important power is regulated, are as simple and exact as those of gravity itself; and it is this circumstance, more especially, which seems to indicate the existence of an universal principle in the movements of organised bodies.

One of my principal objects has been to detect the anatomy by which the reflex power operates; and, although this branch of the inquiry needs much further prosecution, I am, myself, convinced that a peculiar order of nerves, called the excito-motory, not only exist in the cerebro-spinal, but, likewise, in the ganglionic system. The contractile power possessed by plants, has induced many anatomists to conclude that those bodies are provided with some kind of nervous system; and, if it should be proved, hereafter, that the vessels and tubes of vegetables do act in obedience to the reflex principle, it is certain that they must be furnished with organs which, however much they may be modified in their physical characters, correspond in office with the excito-motory system of animals.

It may, perhaps, be thought, that more import-

ance is attached to the anatomy connected with this principle than it deserves; but although no one is more willing than myself to acknowledge the profound spirit of physiology, which enabled Dr. Hall, unaided by the scalpel, to penetrate the veil which has so long obscured the operations of the nervous system; yet it cannot escape the recollection how many theories, none, perhaps, so important, but bearing equally with this the semblance of probability, have ultimately been classed in the number of ingenious but unfounded speculations. Such being the lesson that experience has taught us, it is, perhaps, not too much to assert, that if the physiologist be anxious to establish, by the results of his inquiries, a great principle of the animal economy, he must be satisfied previously to submit his conclusions to the test of anatomy.

It may be proper to add, that the investigations to which this treatise relates, were commenced at the close of the last year; but that, owing to a severe domestic affliction they were for some time interrupted; and, subsequently resumed under circumstances unfavourable to their prosecution.

In consequence of the difficulty which was experienced in making the necessary references,

I much regret that the very valuable researches of Sir G. Blane are noticed in a manner much too cursory in the first chapter. This excellent physiologist was not deceived by the curious phenomena observed upon irritating the hinder part of the body, after the section of the spinal cord; for he distinctly states that they are not attended with consciousness or sensation. His words are "these facts clearly show that instinctive, or rather automatic motions may be exerted, without the intervention of the *sensorium commune*; and, therefore, without sensation or consciousness."*

* Select Dissertations, p. 262. Dr. Hall has given the whole paragraph, of which the above is an extract. See Memoirs, p. 54.

ERRATA.

Page 120, line 14 from top, for *compound* read *component*.
Page 156, line 9 from bottom, for *escholtzia* read *eschscholtzia*.

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CONTENTS.

EXPLANATION OF THE PLATE.

The fibres of the Spinal Nerves become so delicate, after they have penetrated the Pia Mater, that it is impossible to convey, by a plate, the exact appearances of their anatomical disposition.

Fig. 1.—Anterior surface of the Spinal Cord (in a dog), showing the true roots of the Anterior or Motor Nerves.

A. Anterior Median Fissure.

B. Anterior Lateral Fissure.

C C. Anterior roots of the Nerves, dividing into—*c'*, Cerebral, or true Volition Fibres; and *c''*, Spinal, or Reflex, seen dipping into the grey matter of the cord.

Fig. 2.—Posterior surface of the Spinal Cord (in a dog).

D. Posterior Median Fissure.

E. Posterior Lateral Fissure.

F F. Posterior roots of the Nerves, dividing into *f'*, Cerebral, or true Sensiferous Fibres; and *f''*, Spinal, or incident Fibres, seen entering the grey substance of the cord.

Fig. 3.—Plan of the Spinal Cord and Spinal Nerves, intended to show the arrangement of the grey and fibrous structures, represented in profile.

A. Anterior surface of the Cord.

B. Posterior surface.

c. Grey matter.

d. Anterior or motor root of the Spinal nerve, dividing into two orders of fibres.

e. Posterior, or Sentient Root, dividing into two orders of fibres.

f. Cerebral Fibres of the Anterior Root, or pure Volition Fibres.

g. Cerebral Fibres of the Posterior Root, or pure Sensiferous Fibres.

h. Spinal Fibres of the Anterior Root, or Reflex Fibres.

j. Spinal Fibres of the Posterior Root, or Incident Fibres.

Fig. 4.—Section of a portion of an articulated animal, enlarged to explain the character of the excito-motory phenomena, in progression. The parts are represented as seen from above,

a b. Gangliated Spinal Cord.

c. Ganglion.

d. Interganglionic Cords.

f. Direction of the impression of a physical agent, acting on the skin of the foot, passing along the Incident Nerve to the true Spinal Cord, which, in this instance, consists of a Ganglion.

g. Direction of the Reflex action, passing from the true cord to the muscles of the foot, by the Reflex Nerve.

OBSERVATIONS

ON THE

ERRATA.

Page 9, line 1, for *or* read *for*.

Page 11, line 7 from the bottom, for *arteries* read *actions*.

Page 14, line 7 from the top, for *are not accurately described* read *are not so accurately described*.

Page 54, line 3 from the bottom, for *indisputed* read *undisputed*.

Page 82, line 11, for *anencefalous* read *anencephalous*.

Page 84, line 6 from the bottom, for *are diminished wholly, or only suspended during sleep*, read *are diminished only or wholly suspended during sleep*.

Page 127, line 3 from the bottom, after *excito-motory*, substitute a *comma* for a *period*.

Page 133, line 7 from the bottom, for *a theory is*, read *a theory which is*.

Page 151, line 12 from the bottom, for *central* read *cerebral*.

Page 156, line 4 from the bottom, for *enemone* read *anemone*.

Page 158, line 8 from the bottom, after *portio major*, omit the comma; line 4 from the bottom, for *portio major, trifacial*, read *portio major of the trifacial*.

Page 159, line 4 from the top, for *trificial* read *trifacial*; line 5 from the bottom, for *optic* read *otic*.

details have been collected, at the expense of great and unceasing labour; yet, as the general laws on which they depend are in a great degree unknown, the systematic treatises on this subject abound in obscure, and even contradictory statements.

A question which has particularly engaged the attention of physiologists, concerns the properties of the spinal cord, on which subject, however, we possess nothing but the most conflicting evidence; for, whilst the phenomena presented by those anencephalous fœtuses which have for a time survived their birth, and the results obtained from vivisections made on the different parts of the brain, seem to establish the fact that sensation and volition are properties of the spinal cord, including under that term the medulla oblongata; the observation of the effects of accident and disease in the human body, which in such a question is so much more worthy of confidence, distinctly proves, that in no instance whatever does an organ deprived of its connexion with the brain, retain its sensation, or the capacity for voluntary motion. Another element has lately been added to the confusion already existing, by the discussion which has arisen respecting the reflex function of the spinal cord; one party maintaining that the phenomena observed are the result of sensation and volition, whilst the other, more justly as I conceive, contend that the excito-motory acts are totally independent of feeling and the will.

It is evident that the latter question is only a part of that more general one, which relates to the real seat of sensation and volition,—whether, that is to say, these properties are restricted to the brain, or whether they are also possessed by the spinal cord. As the existing opinions are so conflicting, and especially as views have been lately advanced by some very high authorities, which appear to me erroneous, it becomes necessary, in order to elucidate my own views, to make a brief exposition of the information we at present possess on this interesting subject.*

* It would be inconsistent with the object of the present treatise to

In entering upon this inquiry, it must be remarked that most physiologists imagine the medulla oblongata is endowed with qualities of a different nature, from those which belong to the other parts of the spinal cord; and although I am myself of opinion that the difference is one of degree only, and not of kind, it will yet be desirable to consider the endowments of the cranial and vertebral portions separately from each other.

With respect to the latter, or vertebral part, it has been ascertained, by the experiment of removing the head, that cold-blooded animals, under such circumstances, still retain the power of producing combined motions, whenever the body is touched or irritated. Thus, Whytt remarked, that, after decapitation, frogs and serpents performed movements of the limbs or entire body, consequent upon the application of a stimulus to the skin; and he further proved, that these motions were dependent on the spinal cord, ceasing when that organ was destroyed.*

examine, or even to name, all the various theories which have been advanced; this is the less necessary, as the reader who may be desirous of obtaining such details, will find a most able and comprehensive view of the existing opinions on this subject, in the last edition of Dr. Bostock's Elem. Sys. of Phy., chap. x.

* It is essential to distinguish between the contraction induced in a muscle, or muscles, by the application of a stimulus to the skin, and that irregular contraction, or twitching, which is caused by immediately pricking, or otherwise exciting, the fibres of the muscle itself; in which case, as Whytt has accurately stated, the fibres which are irritated are only affected with a weak, tremulous motion, the neighbouring muscles remaining at rest. It is also necessary to notice, that the reflex action has nothing in common with the contractions induced by pricking a divided nerve; for whilst, in the latter case, there is merely a convulsive action of the muscles supplied by the nerve that is touched, in the former, definite and combined contractions are produced, varying according to the part in which they occur, but either being *of a preservative character*, (as where a part of the body is withdrawn from a source of irritation,) or *resembling the motions which the function of the organ requires.*

Similar effects were noticed by Haller, as occurring in warm-blooded animals; and Sir G. Blane also showed, that after the section of the spinal cord in young kittens, if a heated wire was applied to the skin of the foot, the leg was suddenly retracted.*

The power which these experiments prove the spinal cord to possess, of reflecting impressions made on the skin, in such a manner as to determine combined actions of the muscles, was rendered still more apparent by the investigations of Mr. Mayo. This distinguished physiologist ascertained that the cord not only possesses this power when entire, or when only simply divided, but likewise, that individual segments of it are endowed with a similar property; so that, if the cord be cut through, both in the neck and the back, the irritation of the skin in either part was found to produce a convulsive action of the muscles of that part alone.† That this power is not confined to the spinal cord where contained in the vertebral canal, was shown by another experiment made by Mr. Mayo; in which the segment, composed of the optic tubercles and the crura cerebri, having the attachment of the optic and third nerves, being insulated from the brain and medulla oblongata, it was found, that on pricking the stump of the optic nerve adhering to the optic tubercle, the iris contracted.

The result of these, and of other researches which might be adduced, distinctly proves that the spinal cord, quite independently of the brain, possesses a property in virtue of which it is able so to transmit impressions made on the skin, as to excite definite muscular contractions. This most remarkable faculty has necessarily given rise to much speculation as to its nature; and the experiments

* Select Dissertations, p. 262.

† Anat. and Phy. Comment. No. 2, p. 18.

just related have induced all physiologists, with the exceptions hereafter to be mentioned, to consider, that sensation and volition are either properties enjoyed by the spinal cord itself, or that those powers remain for a certain time in the cord, after it has been cut off from the brain.

One of the earliest observers of these phenomena, Whytt, is evidently of this opinion, for he says, "Since, therefore, the bodies of vipers make just the same kind of motions, when pricked with a sharp instrument, two or three days after losing their head, heart, and other bowels, as if they were entire, we are naturally led to conclude, that they are still in some sense alive, and endued *with feeling, i. e.* animated by a *sentient principle.*" The same conclusion is drawn by Haller.

Le Gallois distinctly attributes to the spinal cord the power of exciting sensation, and he also implies the existence of volition: his words are "La section de la moëlle a évidement établi, dans le même animal, deux centres de sensations bien distincts et independans l'un et l'autre; l'on pourroit même dire deux centres de volonté, si les mouvemens que fait le train de derrière, quand on pince la queue, ou bien une des pattes posterieures supposent la volonté de se soustraire au corps qui le blesse."* it is well known that Magendie and Desmoulins, from their experiments, concluded that sensation and volition remain after the removal of the cerebrum and cerebellum; it is stated "si l'on retranche successivement d'avant en arrière, sur un animal dont on a ouvert le crâne, toutes les parties du cerveau, puis les lobes optiques, puis le cervelet tout entier, de manière que la dernière tranche passe au-devant de l'insertion de la

* Exper. sur la Principe de la Vie, p. 60.

cinquième paire, l'animal continue d'avoir la conscience de toutes les sensations, moins celles de la vue."*

In the report made to the Institute respecting the inquiries of Flourens, Cuvier contends that the destruction of the brain does not destroy sensation, which he supposes is essential to the production of the phenomena observed in such cases.†

The views advanced by Mr. Mayo require a more detailed notice, because his authority on all questions relative to the nervous system is highly and justly esteemed; and particularly because in the last edition of his Outlines of Physiology, he has assumed the credit of having established the principle on which the phenomena above stated depend; whilst that work, as well as his Anatomical Commentaries, contains statements calculated, as I conceive, to perpetuate the errors which have so long and so generally prevailed.

In referring to the claims of Dr. M. Hall to the discovery of the true character of the reflex function of the spinal cord, Mr. Mayo states, that in 1823, and subsequently in his Physiology, he had carefully distinguished the phenomena in question from the agency of sensation and volition. The passage which in his Anatomical Commentaries more particularly bears upon this point is the following:—"An influence may be propagated from the sentient nerves of a part, to their corresponding nerves of motion, *through the intervention of that part alone of the nervous centre, to which they are mutually attached*" This distinctly shows, as I have already stated, that Mr. Mayo had demonstrated several years ago, the power of the

* Anat. des Syst. Nerv. p. 560. In this work facts are mentioned, which are supposed to indicate the persistence of volition also under the above circumstances.

† Flourens, Recher. Experim. p. 78.

various segments of the spinal cord to exercise the reflex action; but this passage does not touch the main question as to the influence of sensation and volition in these instances. After relating the experiment above mentioned, in which the cord was divided in two places, the following observations occur:—"It may be said that this experiment of making different nervous centres by division of the spinal marrow, admits of explanation, by supposing the principle of volition, and sensation also, to continue for a short period extended to the portions separated from the brain; a conjecture consistent with, though not established by, the very curious fact that the movement of the leg of an animal thus circumstanced, when the sole of its foot is irritated, is accurately the gesture which the animal employs when, in undisputed possession of its sensation, it retracts its limb from a similar aggression.*" Now, the whole tenour of this passage points to the conclusion, that the reflex action of the spinal cord *is* dependent on sensation and volition. In the last edition of his Outlines of Physiology, in fact, Mr. Mayo adduces these identical experiments as a proof that "each segment of the double (spinal) cord from which a pair of nerves arises, has in itself a mechanism of sensation and instinctive action."† In this work it is likewise stated that "the spinal marrow and the medulla oblongata are experimentally shown to be sufficient for sensation, instinct, and volition,"‡ and that "the brain in man is not necessary for sensation and the commonest instinctive actions."§ With these statements before us, it is difficult to admit that Mr. Mayo has made that distinction between the reflex action and sensation, which he claims.

* Anat. Comment. No. 2, p. 18. † Out. of Phy. 4th edit. p. 212.
‡ *l. c.* p. 238. § *l. c.* p. 210.

The only authors, in fact, who have clearly announced that what have been designated the excito-motory phenomena are totally independent of sensation and volition, are Dr. M. Hall and Professor Müller. But previously to considering the important discovery of these distinguished physiologists, it will be proper to allude to the views at present entertained, respecting the functions of that portion of the cord which is lodged within the cranium, or of the medulla oblongata.

The opinions on this subject are principally founded on the observation of anencephalous fœtuses, that have lived for a time after birth, and on vivisections practised on the different parts of the encephalon; for, as to the evidence afforded by disease, it is so far from corroborating these opinions, that physiologists have experienced an insurmountable difficulty, in reconciling the effects produced by morbid states of the brain in man, with the results obtained by experiments performed on the lower animals. The phenomena observed in the few intances of anencephalous infants, which will subsequently be considered; joined to the very striking facts noticed in the well known experiments of Flourens,* Magendie and Desmoulins, seemed distinctly to demonstrate, both by the negative effects resulting from the ablation of the cerebrum and cerebellum, and the positive evidence afforded by the preservation of the medulla oblongata, that sensation and volition are attributes of the latter organ. This

* As I shall hereafter have occasion to refer to these very interesting researches, it will suffice in this place to state, that although the highest authorities, among whom may be mentioned Cuvier and Professor Müller, conclude from the experiments of Flourens, that sensation and volition are properties of the medulla oblongata; that physiologist himself with much greater reason contends, that those faculties are the peculiar endowment of the cerebral hemispheres. Recher. Experiment. sur les Prop. et les Fonct. du Syst. Nerv. p. 121.

belief has been or some years regarded as an established axiom in physiology; and, in fact, until the real nature of the reflex function of the spinal cord had been explained, it was impossible for physiologists to attribute to any other agency than that of sensation and volition, the free motions of the limbs, the ingestion and egestion of the food, and the movements of respiration, all of which are known to occur in animals when the brain is deficient. The consequence has been, that, with the exceptions of Flourens and Dr. M. Hall, no writer has imagined that these phenomena can be displayed, when all feeling and the will are destroyed.* Even Professor Müller, who has so clearly shown that in the instance of the vertebral portion of the spinal cord, the motions which occur in parts of the body cut off from their connexion with the brain, are independent of sensation and volition, conceives that the medulla oblongata, in addition to being like the cord, a reflector, is also the seat of the influence of the will and of sensation†. He founds this opinion on the experiments of Flourens and Magendie; and has thus, as it seems to me, by misinterpreting their results, fallen into the common error respecting the properties of the medulla oblongata.

It is necessary to remark that some physiologists are of opinion that the spinal cord, independently of volition, has, in some manner or other, a direct influence in the production of voluntary motion.

Sir C. Bell, in an interesting paper on the structure of the brain, has incidentally touched on the question, how far that organ and the spinal cord are respectively interested in the stimulation of the voluntary muscles. After observing that the structure of the cord shows it to be some-

* Sir C. Bell, it is proper to state, considers sensation to be a property of the brain. Phil. Trans. 1834.

† Handbuch der Physiol. I. p. 826.

thing more than a mere nerve, and that in the composition of its cineritious and medullary matter it resembles the brain, this distinguished physiologist proceeds to say, he is induced "to believe that the brain does not operate directly on the frame of the body, but through the intervention of a system of nerves, whose proper roots are in the spinal cord.* From this brief statement, it appears, Sir C. Bell conceives that the spinal cord co-operates in the production of voluntary motion, not merely as the conductor of the volition of the brain, but, also, by its own peculiar power.

Professor Müller likewise considers that the spinal cord, in addition to being the peculiar seat of the reflex function, is, also, immediately necessary to the exercise of voluntary motion; indeed, in some respects, even more so than the brain itself. He says, "the cord is by its motorial tension (*spannung*) the cause of the power of our motions. The intensity of our efforts depends in a great part on this organ. Although, in the normal state, the greatest part of the motor nerves are inactive, if the will does not operate upon them; nevertheless, the strength and duration of the motorial stimulus which the sensorium commune voluntarily produces, depend upon the spinal cord. This organ contains, as it were, a store or provision of motorial power; and, although, by means of its fibres continued from the brain, it acts as a conductor, by propagating the oscillations arising from the sensorium commune, yet the intensity of the following effect depends not only on the strength of the will, but also on the quantity of motorial nervous power which is accumulated in this column."†

A somewhat similar opinion was advocated by the late

* Phil. Trans. 1834, p. 480. † Physiol. I. p. 803.

Dr. Fletcher, who, perceiving from the investigation of the reflex action of the spinal cord, how much this organ is connected with the production of what is commonly called voluntary motion, but which is in reality, in many instances, excited motion, enters into a long argument to prove that the direct stimulus by which the voluntary muscles are excited to contract, does not consist of the volition exerted by the brain, but of some peculiar action of the spinal cord.*

All these details sufficiently prove that the opinions which prevail respecting the seat of sensation and volition, are anything but satisfactory. Although it is with great diffidence that I venture to disagree from so many high authorities, yet, I cannot refrain from expressing my conviction that those physiologists who contend that sensation and volition are properties either of the spinal cord in general, or of that part of it more particularly which is placed in the cranium, are equally in error. I believe it is susceptible of proof, although this has not yet been satisfactorily accomplished, that the brain is the sole organ of sensation and volition; and that the spinal cord is only connected with the production of true voluntary motion, in consequence of one part of its structure serving as the conductor of the volitions of the cerebrum.

But it is certain that the spinal cord has a most important and immediate connexion, with the actions of the muscles which are called voluntary; that it enjoys a power of exciting these to contract independently of the brain; and that it is this circumstance which has been the cause of all the conflicting opinions and evidence, which have been advanced on this subject. The discovery by Dr. M. Hall and Professor Müller, of the real nature

* Rud. of Phy. Pt. II. b. sect. 5 and 6.

of the reflex function of the spinal cord, appears to afford a clue to the whole of this mystery; and when developed to its full extent, is probably capable of explaining most, if not all, of those anomalies which so seriously obstruct the successful cultivation of the physiology of the nervous system.

It was reserved for Dr. M. Hall to penetrate the mystery which had baffled all other physiologists; and to prove, not only that the phenomena which result from the reflex action of the spinal cord are essentially distinct from sensation and volition; but, likewise, to perceive, what had never before been surmised, the necessity of an independent division of the nervous system, equally distinct from the great sympathetic and the true cerebral system, by the agency of which, these peculiar phenomena are accomplished. Until these important distinctions were announced, no physiologist could explain how those motions, which are usually termed involuntary, but which must now be called excited, could take place in muscles of a voluntary character. How, for example, the actions of the diaphragm, which are susceptible of being suspended and otherwise controlled by the will, continue nevertheless during sleep, in coma, in the anencephalous infant, and in animals experimentally deprived of the brain:* how the muscles of the face, which are so immediately under the influence of volition, become excited, together with a multitude of other muscles, in sneezing: how the muscles of the throat, which in speaking and singing are so obedient to the mental impulse, are placed beyond its control in swallowing, coughing and vomiting:

* What can more strikingly evince the utter confusion that prevails in this important branch of physiology, than that the actions of the diaphragm, notwithstanding the most palpable evidence to the contrary, are considered, both by Dr. W. Phillip and Mr. Mayo, to be of a voluntary nature. See Hall's Lect. on the Nerv. Sys. p. 20.

or, in fine, how the muscles of volition can be excited to contract by impressions made on the sentient surface of the skin, when all volition and sensation are destroyed by the section of the spinal cord. These, and a multitude of other apparently conflicting phenomena of the nervous system, may be all readily solved according to the views of Dr. M. Hall.

As these opinions have excited such universal interest, it is only necessary to state, very briefly, Dr. Hall's conclusions. He conceives

1. That there exists a true spinal cord, physiologically and anatomically distinct from that portion of the cord which is strictly an appendage of the brain.

2. That there is a system of nerves physiologically distinct from the sentient and voluntary nerves, called excito-motory nerves, consisting of *incident* nerves, which arise from the skin and certain mucous membranes, and of *reflex* nerves which end in the voluntary muscles. These parts collectively, that is to say, the true spinal cord and the excito-motory nerves, constitute what Dr. Hall designates the true spinal system.

3. That currents of nervous influence may be excited, passing upwards from the skin and downwards to the muscles, through the medium of the incident and reflex nervous fibres.

4. That the true spinal system presides over ingestion and exclusion, over retention and egestion; and, consequently, that its influence is exerted upon the muscles which belong to the entrances and the outlets of the animal frame; or, in other words, upon the sphincters, the muscles of deglutition, and of respiration.

5. That the true spinal system maintains the tone of the whole muscular system.

In his most important work, Dr. Hall has supported his views by numerous experiments; and has particularly

illustrated the value of this theory in the investigation of pathology.*

Nearly at the same time that Dr. Hall published his opinions, Professor Müller developed, in his admirable Manual of Physiology, very similar views respecting the reflex action of the spinal cord.† In the first edition of this work, however, the excito-motory phenomena are not so accurately described as by Dr. Hall, nor are they so carefully distinguished from sensation; still less is there any suggestion as to the necessity of a particular nervous system for the production of these phenomena. In the last edition of the first volume of his physiology, Professor Müller has very fully treated of the reflex action of the cord; and, in most of the essential points, he coincides with Dr. Hall, excepting that there is still no allusion to a distinct nervous system, and that sensation and volition are attributed to the medulla oblongata.‡

Although the great merit of discovering the true character of the reflex function is due to these physiologists, they have not succeeded in supporting their opinions on an anatomical basis; and yet, unless a set of nerves distinct from those of sensation and volition be capable of demonstration, it is impossible to establish the correctness of what, without such evidence, is merely an hypothesis. For since the splendid discovery of Bell, it has been justly admitted, that where there is diversity of function, there

* See Lectures on the Nervous System, p. 11.

† Although the priority of publication must be decided in favour of Dr. Hall, it is evident that these two distinguished physiologists, as Dr. Hall, with that candour which it is so gratifying to notice in matters of this nature, has himself stated, were mutually ignorant of each other's researches.

‡ From some conversation which I have lately had with Professor Müller, I am induced to believe that that eminent physiologist does not admit the necessity of any distinct division of the nervous system, for the production of the excito-motory phenomena. Dr. Hall has pointed out in a paper published in the Lond. and Edin. Phil. Jour. Dec. 1836, the differences between his own views and those of Professor Müller.

must be diversity of structure; or, in other words, that each primitive fibre of the nervous system, has the property of carrying an impression in one direction only,—the fibre of sensation, from the skin to the brain,—the fibre of motion, from the brain to the muscle. By a parity of reasoning, then, it is evident, that if there be in the nervous system, a power of transmitting from the skin centripetal impressions which do not excite sensation; and a capability of reflecting to the muscles centrifugal impressions which do not consist of volition, there needs must be distinct orders of fibres for this purpose. So long, then, as the only known nerves of the cerebro-spinal system, were those of sensation and volition, would the phenomena of the reflex action of the spinal cord have been confounded, as, till these recent researches they always had been confounded, with sensation and volition. The necessity of such a peculiar organization was, as I have already stated, perceived, in the truest spirit of physiology, by Dr. M. Hall; but what he thus saw with the mental eye, he did not succeed in rendering apparent to the senses; and so it has happened, that these views, indicating as they do the existence of a general law of great importance in the economy, still continue to be regarded by most anatomists, either as a repetition of the old and confused opinions respecting sympathetic actions, or as altogether erroneous.

From the preceding account it is perceived, that notwithstanding certain difficulties and anomalies that never have been explained,* the prevailing opinion has been,

* The following passage from Le Gallois, which has been so often quoted, shows the difficulty or rather impossibility of reconciling the hypothesis that sensation and volition are properties of the spinal cord, with the well ascertained fact, that disease of the cerebrum is productive of paralysis—"Quand bien même on n'apercevrait aucun moyen de les concilier, il n'en demeurerait pas moins vrai, d'une part, qu'une affection bornée uniquement au cerveau peut ôter le sentiment et le mouvement volontaire à la moitié

and still continues to be, that sensation and volition are properties of the medulla oblongata, and consequently that they remain after the loss of the brain.

It is further evident, that many writers suppose the spinal cord also to be more or less connected with sensation, and especially with the production of voluntary motion. But although these doctrines are so generally received, there are few physiologists, who do not perceive that they are not only utterly insufficient to explain the phenomena of the nervous system, but that they are daily contradicted by the effects of disease.

Such being the imperfect state of our knowledge, the present inquiry, in which, by an analysis of the evidence we already possess, by experiments carefully conducted, and by a minute examination of the structure of the parts implicated, an attempt is made to establish some more satisfactory principles, will not, I trust, be deemed altogether superfluous.

I propose to consider—

1. The anatomy of the spinal cord, and of the spinal nerves.

2. The physiology of the spinal cord.

3. The extent of the reflex action of the spinal cord in the animal economy.

du corps, et de l'autre, que le sentiment et le mouvement volontaire peuvent subsister et etre entretenus dans un animal décapité. Quelque opposés que ces faits paraissent etre, il faut se souvenir que deux faits bien constatés ne peuvent jamais s'exclure l'un l'autre, et que la contradiction qu'o croit y remarquer tient à ce qu'il y a entre eux quelque intermédiare, quelque point de contact qui nous échappe." Œuvres, Paris, p. 21. Ought we not rather to suspect, when the positive evidence furnished by the observations of disease in the human brain, contradicts the apparent results of our experiments on the lower animals, that in the latter instance where there are such fertile sources of error, we have been led to a false conclusion?

CHAPTER II.

PROPERTIES OF THE GREY AND FIBROUS SUBSTANCES.

It is a point of essential importance to determine the respective properties of the two materials, which compose the central organs of the nervous system; but, owing to their very intimate combination, it is extremely difficult to ascertain the share which each structure exerts, in the production of those phenomena that are displayed by the brain and spinal cord.

The researches which have of late years been carried on with so much success, to ascertain the connexions that exist between the fibrous and grey matter, have led to the revival of an opinion, which, with different modifications, has long been entertained, to the effect that the fibres of the white matter are subordinate to the grey; which, according to this theory, is the sole source of power. This doctrine, which numbers among its supporters the most eminent physiologists of the present day, is, I conceive, capable of being satisfactorily established: as it is, however, opposed to the celebrated hypothesis of Gall and Spurzheim, according to which the office of the grey matter is principally to secrete or form the white fibres, it may be proper, in the first place, to consider how far this last position is tenable.

The views of Gall and Spurzheim are entirely opposed to the laws which regulate the formation of the various organs; for, independently of the fact observed by Professor Tiedemann, that the fibrous matter appears before the grey, the results obtained by developmental anatomy show that the material of the nervous system is, in the first instance, derived from the plastic substance, or blastema of the embryo; and that, subsequently, when the different substances make their appearance, vascular membranes, in the form of canals or vesicles, are provided to aid in the process of development. There is in all this, no evidence to show that the white fibres are derived from the grey matter; on the contrary, the provision of a large quantity of highly organized matter, persisting, it must be remembered, during the whole period of existence, and having no office of its own, but merely to form another and less organized substance, the white, would be an anomaly which has no parallel in the formative process. The blood-vessels of the different constituent parts of the various organs are efficient to their formation; and, in this manner, doubtless, the fibres of the cerebrum and spinal cord, like those of the nerves, in which it must be recollected the grey matter does not exist, are formed, and subsequently nourished by the vascular sheaths in which they are contained.

As it would then be contrary to all analogy to admit the theory of Gall and Spurzheim, it will be proper to consider the facts, which favour the idea of the grey matter being the source of the power possessed by the brain and spinal cord.

In the first place it may be stated as an admitted principle, that the importance of an organ in the economy is mainly dependent on the supply of blood it receives; a proposition which, in the case of the nervous system, is

rendered strikingly apparent by the interesting experiment performed by Sir A. Cooper; in which it was found that the simultaneous compression, either by the thumbs or by ligature, of the two carotid and two vertebral arteries, instantly annihilates the power of the brain and of the spinal cord; and, by paralyzing the diaphragm, causes immediate death.* Now, in this respect it is well known, that the grey matter is pre-eminently distinguished, as with the exception of the lungs and kidney, it is more abundantly furnished with arterial blood than any other organ. Through the kindness of Professor Arnold of Zurich, I have had an opportunity of examining some very beautiful specimens of minute injection of the cerebral substance, prepared by that distinguished anatomist. In these preparations the contrast between the relative vascularity of the grey and fibrous substances is very strikingly perceived; for, whilst the latter is only slightly coloured, the former, owing to the great abundance of its blood-vessels, presents a complete pink tinge. These facts evince not only the paramount importance of the grey matter, but likewise its great superiority over the fibrous substance.

A second circumstance bearing upon the present question is, that *the grey matter increases in quantity in the exact ratio of the nervous energy.* We learn from a comparative examination of the brain, that the intellectual operations become diversified and energetic in proportion as the grey substance is accumulated; and it is in this respect especially, more than in that of relative volume, that the brains of the lower animals differ when compared

* This experiment proves, in a very forcible manner, the immense importance of the blood, in sustaining the actions of those organs on which life depends; and this, not through the slow process of nutrition, but in an immediate and direct manner.

with each other, or with the human cerebrum, the great peculiarity of which consists of the very large proportion of its grey matter, when contrasted with the nerves attached to its base. A very accurate test of the intelligence possessed by different animals, and even by different individuals of the human species,* is thus afforded by the development of the convolutions, or, in other words, of the grey substance; for the so called convolutions of the brain are only another illustration of that principle so beautifully displayed in the formation of the glands, according to which the largest possible quantity of material is contained in the smallest possible space.

But the condition of the cerebro-spinal axis, at the time of birth, affords, perhaps, the most satisfactory evidence on this point. At that period, the grey matter of the cerebrum is well known to be very defective, so much so, indeed, that the convolutions are as it were in the first stage of their formation, being only marked out by superficial fissures, almost confined to the surface of the brain: whilst at this identical period, the spinal cord, owing to the imperfect development of its fibrous part, (which, as will be subsequently shown, is allied with the exercise of sensation and volition,) contains a larger quantity proportionably, of grey matter than it does in the adult; in consequence of which, according to the remark of Pro-

* In advancing this opinion, which has been supported by so many distinguished physiologists, I beg to express my dissent from the conclusion attempted to be drawn from it by some writers, that such a theory displays the character of materialism. The merits of that long disputed question are not touched by the observations offered in the text; for they merely relate to the material instrument by which the nervous power, whatever it may be, operates. Even the inquiry respecting the character of that power, which I consider to be a most legitimate subject of physiological inquiry, has nothing to do with the nature of the soul; the two questions are essentially distinct from each other, and as such they ought to be treated.

fessor Arnold, that matter, which in the adult is placed so deeply in the interior, approaches much nearer to the external surface. Now at this particular time, the true cerebral functions, consisting of the intellectual faculties, sensation and volition, are almost entirely, if not for a brief period totally wanting; whilst the true spinal functions are in full activity. It is impossible to adduce any more striking proof than this, to demonstrate that the extent of the power inherent in the nervous system, depends on the quantity of the grey matter.

Professor Tiedemann, in his valuable work on the development of the brain, has incidentally mentioned a fact which bears on this inquiry: he has found that in the torpedo, there is a mass of grey substance placed in connexion with the fifth and eighth nerves supplying the electrical organs, larger in size than the cerebellum itself, whilst, in the common skaite no such mass exists. An exactly analogous fact is furnished by the comparative anatomy of the lobe of the olfactory nerve; for, in animals distinguished by the acuteness of their smell, that body is remarkably large when contrasted with those in which that sense is less perfect. The object of such formations cannot be mistaken, it is evidently to generate power.

Lastly, it may be mentioned in corroboration of the opinion here advanced, that the grey matter is only met with in those parts of the nervous system, which are known to be the seat of power; that is to say, in the encephalon, the spinal cord, and the ganglions; it is wanting, notwithstanding the assertion of Monro to the contrary, in those parts—namely, the nerves—which are proved not to have the capability of originating power.

The white fibres are merely conductors of nervous power. The negative evidence which shows that the white matter

is not a source of power, is equally as strong as the positive proofs which have been adduced, in favour of the grey substance being the true seat of the nervous energy.*

No one supposes that the fibres of a nerve, when insulated from the brain, possess any other power than that of transmitting impressions; for it is well known that when, in the human body, the connexion between any organ and the cerebrum is destroyed, all the phenomena dependent on sensation and volition cease. In the same way as regards the connexion of a nerve with the spinal cord; so long as the communication is kept up, certain actions are produced upon irritating the fibres of the nerves going to the skin, but which cease as soon as the union with the cord is destroyed. It is, then, well known that a nerve, in itself, has no power of exciting sensation or motion; that, in fact, it is a mere conductor.

But, in proceeding to the brain more difficulty is experienced; because, in this organ, the source of power, the grey matter, and the conductors, the white fibres, are inseparably joined together; in addition to which, as the true anatomy of the cerebrum was perfectly unknown till the researches of Gall,† the influence of old errors is still in operation; and thus, the so called medullary matter of

* It may be stated, once for all, that, in speaking of the grey matter being the source of power, the expression is intended to signify *all* the powers possessed by the nervous system, with the exception of conduction. This explanation is necessary; because, under the term, nervous power, Dr. Wilson Philip has signified a peculiar property, independently of merely transmitting impressions, which he supposes the nerves to possess.

† It is due to the character of this eminent man, and of his pupil, Spurzheim, to state that all our knowledge of the anatomy of the brain and spinal cord, has resulted from their dissections; and even with respect to those splendid discoveries, which have thrown so much light on the functions of the nervous system, I believe that most, if not all, of them may be traced to the same source.

the brain is very generally regarded, as being something more than a mere collection of fibres, which are, in their essential characters, identical with those of the nerves.

The mistake has been caused by the extremely delicate texture of the brain, which has for centuries been the great obstacle in studying that organ; for, whilst in the nerves, which are exposed to motion and compression, the fibres require a certain degree of solidity and resistance, and are therefore provided with a dense neurilema, those those of the cerebrum being altogether removed from the effects of external violence, are so extremely soft, that they are followed with great difficulty. The very beautiful process discovered, however, by Reil, of hardening the brain by prolonged maceration in alcohol, has completely obviated the impediments arising from the natural texture; and has enabled the anatomist to trace the fibrous structure, in all its wonderfully intricate arrangement. The following orders of fibres have, by these means, been demonstrated:

1. The pure sensiferous fibres, proceeding from the spinal cord.

2. The pure volition fibres, proceeding from the spinal cord.

3. The transverse commissural fibres, of which the corpus callosum and pons Varolii contain the principal number.

4. The longitudinal commissural fibres, comprising the fornix, the commissure above the corpus callosum, and the intercerebral commissure.

5. The peripheral fibres uniting the individual convolutions together.*

With respect to the two first classes, as they are con-

* Mayo, Out. of Phy. p. 223.

tinued directly from the sentient and volition fibres of the spinal cord, as they proceed uninterruptedly to the grey matter of the encephalon, and as they retain essentially the same physical characters by which they are distinguished in the nerves, there can be no doubt that they are still merely conductors of the nervous power; that, in fact, as we learn from the late dissections of Sir C. Bell and Mr. Solly, the corpus restiforme going to the cerebellum, and the crus cerebri going to the cerebrum, are nothing else than compound nerves of sensation and volition; and that, like nerves, if their communication with the grey matter of the convolutions be cut off, as happens from laceration of the corpus striatum, consequent upon the effusion of blood in hemiplegia, sensation and motion are lost in those parts of the body to which the injured fibres are distributed. It may, perhaps, be supposed, by some, that the microscopical researches, which have been so zealously prosecuted, especially in Germany, invalidate the above conclusion, inasmuch, as Ehrenberg and many others, contend that the white substance of the cerebrum contains a peculiar set of fibres;—*the varicose,* which are not met with in the nerves, with the exception of the olfactory, the optic, and the auditory. But long experience has shown, that the results of microscopical observations must always be received with the greatest caution, on account of their being so extremely liable to error; an assertion fully borne out in the present instance, as those experimentalists who have admitted these two orders of fibres, have disagreed with respect to their physical characters, upon which alone the distinction attempted to be established can be supported. Not only is there this discrepancy among the advocates of this division; but some eminent anatomists conceive that the particular varicose appearance, of which so much has been

said, is not the result of the real structure of the nervous fibre; but ought to be attributed to the manipulation employed. But, admitting for a moment that there exists in reality, in the brain, a particular set of fibres which are not generally found in the nerves, it is certain that they cannot be the seat of the peculiar powers of the nervous system, as they are met with in three nerves, which are not distinguished by the possession of any properties, not enjoyed by the nerves at large.

As regards the commissural fibres, although their office still remains to be satisfactorily determined, it is at all events certain, from their anatomical disposition, that they cannot be the source of that power which operates through the nerves.

The facts adduced in this chapter are, I conceive, sufficient to prove, that the phenomena displayed in the cerebro-spinal system, are dependent on the grey matter; and, as will appear in the sequel, it is highly probable that the same substance, composing as it does so large a proportion of the various ganglia, has an equally important office in the system of the great sympathetic.

CHAPTER III.

ANATOMY OF THE SPINAL CORD AND NERVES.

Prior to the researches of Gall and Spurzheim the spinal cord was regarded as a prolongation or process of the brain; but it is essential to banish from physiology this idea, which has been the fruitful source of so many errors. The investigations of comparative anatomy, the results obtained by developmental anatomy, and the history of anencephalous fœtuses distinctly prove, that the spinal cord is formed previously to, and independently of, the cerebrum; and that, although from its connexion with the brain it is closely associated with the actions of that organ, yet that it possesses peculiar and highly important properties. But the connexions which exist between the cord and the encephalon, have not hitherto been satisfactorily investigated; because, in fact, the real structure of the cord, without an acquaintance with which this question cannot be decided, is at present not known. It will become apparent in the course of this inquiry, that the spinal cord is composed, as Dr. Hall has announced, of two parts essentially distinct from each other; now the only portion which is at all connected with the brain, is, as will be hereafter shown, the outer part consisting of the white ascending fibres; the other or peculiar portion, being altogether independent of the cerebrum both in

structure and function. Notwithstanding one part is thus immediately connected with the brain, it would be wrong thence to conclude that it was derived from the latter organ; on the contrary there is no doubt that every part of the spinal cord is, like all other organs, developed in its primary formation by the agency of its own blood vessels, ramifying in the vertebral portion of the pia mater, a truth which appears to have been first definitely stated by Desmoulins in the following passage: "il est démontré pour la première fois qu'aucune partie du système cérébro-spinal n'est *produite*, n'est *végétativement poussée* par une autre, mais que chaque partie est formée à sa place par la pie-mère."* The spinal cord, like the cerebrum and cerebellum consists of grey matter and white fibres, each of which requires a separate notice.

Grey Matter.—The peculiar form of this substance was pointed out by Bellingeri; and subsequently, Mr. Mayo has more minutely described its arrangement. It consists of two corresponding lateral portions, which form together a kind of ring, within which is placed some white fibrous matter; so that when a section is made across the cord, a spotted appearance is presented, in consequence of the intermixture of the two substances. The source and connexions of the white fibres thus placed within the grey are not known; but it is certain that they must in part, if not entirely consist of certain fibres, which pass into the grey substance from the spinal nerves. In this particular disposition, which is constant in vertebral animals whenever the grey matter can be sufficiently distinguished by its colour, two things require to be noticed:—1. The peculiar crescentic shape; this depends on the anatomical connexions of the nerves, for, as some fibres, hereafter to

* Anat. des Syst. Nerv. p. 241.

be described, pass both from the anterior and posterior roots into this grey substance, the junction is favoured by one horn being turned forwards and the other backwards. 2. The semilunar processes contained in the two lateral columns, are invariably joined together by an intermediate band of grey matter, which stretches across the median plane, just behind the bottom of the anterior median fissure; in this manner a connexion of the highest importance is established between the two sides of the spinal cord, and, consequently, between the two sides of the body.

By making a longitudinal section of the cord in its whole extent, it is seen that the grey matter, which is analogus in office to the nodules possessed by the articulata, is not as in those animals interrupted in the intervals between the attachment of the nerves, but passes continuously from below, upwards. This section also, enables us to trace the extent of the grey matter of the cord in the direction of the brain, a point of importance in reference to the peculiar functions of the former organ. Although it varies very much in colour, and is more or less intermixed with fibrous substance, it may be observed to pass continuously through the medulla oblongata, the pons Varolii, the optic thalami, and the striated bodies, on the outer border of which it is known to cease; never in this direction becoming continuous with the grey matter of the convolutions. The grey matter of the crus cerebri towards the inner side, is also joined with that of the pons Tarini, tuber cinereum, locus perforatus anticus, and thus with the neighbouring convolutions of the anterior and middle lobes of the brain. Although there is no direct junction between the grey matter of the cord and that of the optic tubercles, yet as these bodies are united with the optic thalami by grey substance, they are thus also brought into connexion with the cord itself.* In the

same way as the influence of an impression is transmitted from one side of the cord to the other, by the transverse process of grey matter, it is probable that by these connexions in a longitudinal direction, impressions, if sufficiently intense, are so transmitted that all the muscles may be stimulated, as happens in violent coughing and sneezing, and even probably in traumatic tetanus, from the head to the foot.

The relative proportion of the grey matter is much greater in young than in adult animals; a fact which is the more remarkable when it is recollected that exactly the reverse obtains in the cerebrum, the convolutions of which organ in very early life are so extremely imperfect. This preponderance of grey matter in the cord of the human fœtus and in that of the higher vertebrated tribes, is an evident approximation to the permanent formation of the lower classes of animals, especially of the articulata; and in both instances is doubtless connected with the extraordinary activity of the spinal cord.

Fibrous Matter.—The external surface presents certain fissures, dividing the cord into a number of columns; of these fissures, two are placed on the median plane, one on the anterior, and the other on the posterior part; besides these there are on each side two others, the anterior and posterior lateral. The median fissures of which the anterior is much the deepest, are for the reception of processes of the pia mater, which not only serve to convey blood vessels towards the interior, but likewise to support and steady the divisions or columns of the cord; the anterior and posterior lateral fissures also give entrance to blood

* I allude here to the continuous connexions of the grey matter; there exist of course in addition, the various communications between the cord and the brain, which are established by the fibrous structure.

vessels, but in addition they transmit certain filaments of the spinal nerves, which in these situations dip inwards towards the central part of the cord.

By means of the furrows just mentioned, the spinal cord is divided on each side, into an anterior, middle, and posterior column, all of which as may be seen by the examination of the part when quite recent, are composed of longitudinal fibres.

It has been very generally admitted that of these columns, the anterior is for the transmission of volition, and the posterior of sensation, whilst the middle has been supposed by Sir C. Bell and others, to be in a more especial manner connected with the movements of respiration. But it is very doubtful if all this be correct; for although the spinal cord undoubtedly contains a number of fibres anatomically and physiologically distinct from each other, for the transmission of volition and sensation; yet is by no means certain, that these are placed in the anterior and posterior columns respectively. On the contrary, Sir C. Bell has himself stated, that he has not hitherto succeeded in tracing a connexion between the posterior or sensitive roots of the nerves and the posterior column; and Mr. Swan remarks that there is a direct line of separation, between the anterior and posterior columns placed next the median plane, and that lateral part which gives origin to the nerves. My experience entirely coincides with this latter statement; as, notwithstanding the most careful examination, I have never been able to trace any fibres from the nerves into the fasciculi composing the anterior and posterior columns; the anterior and posterior lateral fissures appear definitely to limit the two roots. As the properties of these columns will be again noticed in a future chapter, it is only necessary to remark further, that their fibres approaching the medulla

oblongata, form a distinct decussation not only from side to side, as is seen in the corpora pyramidalia, and in the cords lately described by Sir C. Bell, but also as Mr. Solly has shown from before, backwards; that after this remarkable disposition, the fibres are still continued uninterruptedly upwards, till they reach the convolutions of the cerebrum and the laminæ of the cerebellum, where they terminate, after presenting a connexion with the grey matter, somewhat similar to the incrustation of the white fibres in the corpus striatum.

On opening the anterior median furrow and separating the two lateral colums, a white layer is perceived at the bottom, the direction of the fibres of which it is difficult to determine; a somewhat similar structure is seen in the posterior median fissure. Gall and Spurzheim have represented a commissure consisting of transverse fibres joining the lateral columns; and Mr. Swan speaks of transverse threads passing from one side to the other. These fibres, however, I have satisfactorily distinguished; and it is probable that anatomists have been misled by the supposed analogy of the brain, in which organ the grey masses placed on the two sides of the median plane are united by true commissures; but the spinal cord presents this great difference, that the lateral portions of its grey matter, are directly continuous with each other across the median line.

Anatomy of the spinal nerves.—The inquiry respecting the structure of the spinal cord, requires us to consider the anatomical characters of the spinal nerves.

Each of the compound nerves divides, as is well known, into an anterior and posterior root, separated from each other by the ligamentum denticulatum, and apparently terminating in the lateral fibrous columns above described. The majority of anatomists have rested satisfied with

noticing the connexion which the nerves present with the mere *surface* of the spinal cord, regardless of any other or deeper relations which may exist; but it is certain that such a mode of proceeding is quite insufficient, if any attempt be made to elucidate the physiology of the nervous system, by means of its anatomy. Some attempts have, however, been made to follow the two roots beyond the external surface. Although Vicq. D'Azyr had formed a similar conjecture, it appears that Gall was the first anatomist who distinctly announced that the spinal nerves are connected with the grey substance of the cord. Bellingeri subsequently adopted this opinion; but he, with justice, opposed the idea of Gall, that all the fibres of the nerves are joined with the grey matter. Bellingeri attributes, both to the anterior and posterior roots a triple origin; the former arising by two of its roots from the white fibrous parts, and by the third root, *perhaps*, from the grey matter; the latter arising by two roots, from the fibrous part, and by the third from the posterior horn of the grey substance. Mr. Mayo, who in one place distinctly affirms that the origin of a nerve is always in part from grey matter, speaks more doubtfully of the double connexion with the grey and fibrous substances; for, when treating of the spinal nerve, he says, that the filaments of the two roots *appear* to be partly continuous with the white fasciculi of the cord, and partly to originate in the interior of the grey matter. In an earlier edition of his Physiology, Mr. Mayo has given a representation of this two-fold connexion, which is, however, very incorrect, and has been omitted in the later editions of that work.

Keuffel, Ollivier, and Weber likewise state that the nervous fibres may be followed into the grey substance, a connexion which is also admitted by Professor Arnold.

Several distinguished anatomists deny, however, the possibility of demonstrating the union of the fibres of the nerves, with the grey substance of the cord. Sir C. Bell, in allusion to this subject, says, "some authors describe these roots as derived from the cineritious matter; this is quite at variance with my dissections." Bellingeri himself is not certain that the anterior root is thus connected; whilst Desmoulins denies the connexion altogether. This physiologist, indeed, contends that the grey matter does not exist in the spinal cord of reptiles and fishes, but that there is in the centre a canal filled with a serous fluid. This statement is, I believe, altogether erroneous; for, although it may be impossible to demonstrate, in the cord of these animals, the presence of a substance distinguished by its grey colour or consistence, this circumstance is not sufficient to prove that a structure, possessing the same properties as the grey matter, does not exist; for it is acknowledged that the mere physical appearances of this and other parts of the animal body, the muscles, the blood, the urine, &c. are subject to the most remarkable variations. Another circumstance adduced by Desmoulins, to invalidate Bellingeri's opinion, is, that in serpents, the spinal nerves have each only one root; this assertion, however, is not only opposed to the uniformity of type, which is so strikingly displayed in the nervous system throughout the animal kingdom, and of which the discovery, by Newport, of the double root of these nerves in the articulata is so beautiful an illustration, but the statement itself has been distinctly disproved by Mr. Mayo, who found, upon carefully opening the vertebral canal in a python, that the nerves arise, as in other vertebral animals, by two roots.

Rolando also describes the nerves as being connected only with the white substance; and Professor Müller

observes that the manner according to which the primitive fibres of the nervous roots are joined with the primitive fibres of the spinal cord, is not yet known. In his work on the anatomy of the nerves, Mr. Swan, in alluding to the belief that the nerves always originate in the grey substance says, that there exists considerable doubt as to the correctness of that opinion.

In considering the interesting phenomena related by Dr. M. Hall it occurred to me, that it might be possible to demonstrate the separate existence of what he has called the incident and reflex fibres; and I was thence induced to dissect, with much care, the two roots of the spinal nerves. After repeated examinations, I satisfied myself that each was connected both with the external fibrous part of the cord, and the internal grey substance. The following is what appears to be the structure: after the two roots have perforated the theca vertebralis, and so reached the surface of the cord, it is well known that their fibres begin to separate from each other; of these fibres some are lost in the white substance, whilst others entering more deeply into the lateral furrows, are found to continue their course, nearly in a right angle with the spinal cord itself, as far as the grey substance in which they are lost. But this arrangement has no resemblance to the distinct division into fasciculi depicted by Mr. Mayo; on the contrary, it is with great care only that small, delicate, and individual threads or striæ, as it were, are traced, dipping into the lateral fissure, and at length joining the grey matter. This difficulty is owing to the fact, that whilst the fibres on the outer surface of the pia mater adhere very intimately with that strong membrane, on its inner surface, the neurilema becomes so extremely delicate, that the fibres lose much of their firmness, and break on the application of the least force; an accident which

always happens, if the pia mater be raised from the surface of the spinal cord, beyond the point where the nerves are attached. When the filaments have penetrated into the fissure, they lose their rounded figure and become flattened, and are then seen passing to the grey substance at a right angle to the longitudinal fibres of the cord. *(See pl.* 1. *fig.* 1, 2.) It is extremely difficult, owing to the delicacy of the parts, to determine the exact relations which exist between the above filaments and the grey matter; but in a few dissections, I have been able to perceive these fibrils running like delicate striæ in the grey substance. In one instance the fibres being more distinct than usual, an appearance was presented having a remarkable resemblance to that which is seen, on making a section of the corpus striatum in a recent brain, after the method of Spurzheim. My friend and colleague Mr. Cooper, in this case counted distinctly five separate fibrils passing from the anterior root of one nerve, and there were some other fibres derived from the same root, which were not so plainly seen.

From numerous examinations I am induced to believe, that whenever the white fibres of the nervous system become connected with the grey substance, whether in the different masses of the brain, in the spinal cord, or in the ganglions, the arrangement is similar to what is seen in the section of the corpus striatum to which reference has just been made. The fibres become as it were encrusted with the grey matter, a disposition which may even be seen by a careful inspection in the convolutions of the cerebrum, in which the radiating fibres of the crus cerebri are observed like delicate striæ.

In examining the roots of the nerves I have always relied on the assistance of the naked eye only, avoiding, for fear of deception, the use of a lens; it also appeared to

be preferable to dissect the parts quite in their recent state, so that the natural structure was entirely preserved. The method of Reil which is so useful in tracing the fibres of the brain, is quite inapplicable in the present case; and Bellingeri has shown that the use of acid renders it very difficult, to distinguish the nervous filaments from the blood vessels.

The structure above described, I had ascertained several months ago, and had, at that time, demonstrated it to several of my friends: but on visiting Germany I found so much scepticism, or rather disbelief, as to the alleged connexion with the grey matter, more especially as regards the anterior root, that I very carefully repeated the dissection several times with the aid of an excellent anatomist, Professor Bischoff of Heidelberg, to whom I am much indebted for the facilities he afforded me of prosecuting the inquiry. In every instance in which the parts were sufficiently favourable for examination, I distinctly traced the connexion of both roots with the grey substance; and it is very satisfactory to me to be able to confirm this, by the testimony of Professor Bischoff, who, although he had shared in the doubts before mentioned, has given me his permission to state, that he is convinced by his own examinations that the structure above described really exists.*

* As so much care is required to demonstrate in a satisfactory manner the anatomical relations of the spinal nerves, it will not probably be deemed superfluous to describe the manner in which their connexions with the cord may be best displayed. It is necessary to examine the cord *immediately after death*, the delay even of a few hours by softening the parts, is injurious; and if the dissection be longer deferred, success is impossible. Great advantage is derived from placing the cord immediately after its removal from the body in a very weak mixture of alcohol and water, as by this means firmness is given to the parts without rendering them crisp and brittle, as happens if strong spirit be employed; it is, however, necessary to harden some portions

From careful dissection, I am convinced that it is only a part of the fibres belonging to the two roots which are attached to the grey substance, and that a considerable number of threads are lost in the fibrous part of the cord. The exact mode of their connexion, however, with this latter substance is not known. Sir C. Bell supposes that the superficial layers of the cord furnish the roots of the higher nerves, and that the deeper layers go off to the roots of the nerves as they successively arise; and Mr. Mayo states that white threads at intervals detach themselves from the cord to contribute to the formation of the

in alcohol, in order to trace the direction of the external fibres of the cord. The parts should be dissected with very fine instruments whilst immerged in the fluid. I have met with most success by dividing the pia mater at the median fissure, and very cautiously raising it as far as the lateral furrow, leaving its connexion with the fibres of the nerves intact; it is then necessary to open either the anterior or posterior lateral fissure according to the root examined, at a little distance above the exact place, where the nerve which is to be dissected is attached to the cord; when by cautiously proceeding to open the fissure, the threads which dip into the grey matter are perceived. In the dissection of the cranial nerves, a similar method should be pursued; the pia mater should be carefully raised at a little distance from the attachment of the nerve, but in every case it is desirable not to disturb the connexion of that membrane with the nervous fibres themselves. It is particularly necessary in prosecuting the dissection, to guard against a deceptive appearance connected with the passage of those blood vessels, which pass into the lateral fissure in order to reach the internal grey substance. Without due precaution, these vascular branches may themselves be readily mistaken for nervous fibrils; but they especially are liable to be productive of error, because when they are made tense, they cause those portions of the longitudinal fibres of the cord which are left between them, to assume exactly the appearance of flat transverse fibres; this circumstance probably mislead Gall, and induced him to suppose that all the fibres of the spinal nerves were connected with the grey substance. I have constantly noticed that after the anterior root has perforated the theca vertebralis, a kind of division takes place of its fibres, and that the posterior or those nearest the ligamentum denticulatum, are the principal of those which subsequently plunge into the grey substance; an attention to this fact will facilitate the examination.

spinal nerves. According to Mr. Swan, after the removal of the nervous medulla by the use of a solution of potassa, the roots of the nerves may be seen to extend into the cellular structure, constituting the neurilema of the fibres of the cord. Notwithstanding these statements, it is doubtful if the actual junction of the fibres of the nerves with the fibres of the cord has ever been seen. Those nervous fibrils which are lost in the white part of the cord, are so very delicate after they have passed through the pia mater, that they cannot be traced with the naked eye; and I have found after repeated examinations, that it is impossible to perceive the mode of their junction with the fibres of the spinal cord, by the aid of microscope, in consequence of the thickness and opacity of the pia mater by which they are covered. There cannot, however, I conceive, be any doubt that there is a direct continuity between these nervous filaments, and those fibres of the cord which ascend longitudinally to the brain, and which are subordinate to the exercise of sensation and volition.*

The connexions of the cranial nerves have been traced with much care and accuracy by Mr. Mayo, and more recently by Mr. Solly. It is, therefore, only necessary to notice some facts, which tend to elucidate the subject of the present inquiry, and which hitherto have either not been pointed out, or not considered in reference to the reflex action. By minute dissection it becomes apparent, that these nerves resemble those of the vertebral canal, as from their similarity in function might be anticipated, in being attached both to the grey and fibrous substances;

* See plate 1, figures 1, 2, 3. The two former of these figures are copies of drawings made by M. Wagner of Zurich, who is so justly celebrated for the accuracy of his designs of the nervous system, from dissections made by myself. Figure 3 contains a plan, by which it is hoped the intricate arrangement of the spinal cord and its nerves, may be more easily comprehended.

their connexions indeed, are in some respects more easily traced, in consequence of several of them arising in large trunks; whilst the two roots of the spinal nerves are spread out into single threads when they reach the cord.

In this respect, the third, or motor oculi, is particularly distinguished; and as it may, with strict propriety, be received as the type of the motor nerves of the spinal cord, its anatomical relations demand special consideration. It is stated by Mr. Mayo, that this nerve arises by many fibrils, from the black matter in the crus cerebri. This account is perfectly correct, as far as it extends, but it is not complete; for, as Mr. Solly has shown, some of the fibres are attached to the motor cord in the pons Varolii. But what is particularly interesting is that after the fibres have spread out into the grey matter, or locus niger, some of them may, with care, be followed into the fibres which constitute the upper portion of the crus. Now, this part of the crus cerebri has been described by Sir C. Bell, as receiving certain fasciculi derived from the posterior or sentient column of the spinal cord, where it forms the calamus scriptorius of the fourth ventricle, and which subsequently pass upwards, through the thalami nervorum opticorum, to the cerebral hemispheres. In this manner, as the optic nerve in its origin is united with this tract, an intimate relation is established between it and the motor oculi; which, I conceive, is connected with the interesting phenomenon noticed by Mr. Mayo, and to which allusion has already been made, that, on pinching the divided cerebral end of the optic nerve, the iris contracts.

In considering the disposition of the incident and reflex filaments of the posterior and anterior roots of the spinal nerves, it occurred to me, that, after being incrusted as it were by the grey matter, like the fibrils of the portio

major of the fifth, in their course through the Gasserian ganglion, these two orders of fibres might become continuous with each other, and thus offer a satisfactory explanation of the mode in which impressions made on the nerves of the skin, are transmitted to those of the muscles; and although, owing to the extreme delicacy of the structure, I have not succeeded in tracing this connexion, the analogy of the third nerve renders it very probable that such an arrangement of the nervous fibres does in reality exist.

The sixth, or abductor nerve, is usually described as arising from the corpus pyramidale; but, if the longitudinal fibres of that body be cautiously separated with the point of a fine instrument (a cataract needle, for instance), it will be found that the larger part of the nerve sinks deeply into the substance of the medulla oblongata, and there, assuming the form of a flat cord, at length reaches the grey matter. It is difficult to perceive with what fibres of the cord this nerve is connected.

The facial nerve, which, at the lower edge of the pons Varolii, closely approaches the descending trunk of the portio major of the trigeminal, seems to be joined, by a few fibres, to the grey matter in the interior of the pons, and upper part of the medulla oblongata.

The sublingual nerve, by raising the pia mater as far as the outer border of the pyramidal body, may be observed to send a few fibres into the grey substance placed on the inner side of the corpus olivare.

The portio major of the fifth, and the pneumo-gastric, in consequence of the very important part they bear in the excito-motory phenomena, require to be especially considered. The former passes, as it is known, through the whole substance of the pons Varolii, and ultimately reaches the posterior column of the medulla oblongata.

In this situation, closely approaching the origins of the auditory, facial, glosso-pharyngeal, and pneumo-gastric nerves, it becomes attached not only to the white fibres, but also to a mass of grey matter, apparently continuous with that which is placed in the floor of the fourth ventricle. The remark of Mr. Mayo, that this portion of the fifth and the portio dura rise together, is full of physiological interest.

As regards the attachment of the glosso-pharyngeal and vagus, some of their fibres, after passing very deeply through the ascending fasciculi of the corpus restiforme, reach the grey matter placed in the posterior part of the medulla oblongata; the connexion with the fibrous structure is not so evident. Mr. Solly considers the corpus olivare to be the ganglion proper to the pneumo-gastric nerve; but no fibres of the nerve can be traced into the grey matter of that body, in the human brain. Two roots of the vagus have been spoken of, but it is difficult to demonstrate them; nor, although the two portions of the glosso-pharyngeal may be seen in the foramen lacerum posterius, where that nerve presents the ganglion discovered by Müller, have I been able to trace them as separate roots into the medulla oblongata; in both of these instances, however, there is little doubt that two roots do exist.

I have deferred saying anything of the comparative anatomy of the spinal cord, until what appears to be the real anatomy of the spinal nerves had been explained; for it is only when this knowledge has been acquired, that the nature of the varieties observed in the cord of different animals can be properly appreciated.

We learn from the comprehensive researches of modern anatomists, that whilst, in the vertebrata, the brain bears no definite proportion to the size of the nerves belonging to an animal, and to its powers of motion, which ought to

have been the case if the nerves were merely an appendage of the former, an exact relation always exists between the size of the nerves, and of the spinal cord. As regards the vertebral animals, this fact is not only demonstrated, with respect to the cord regarded in its whole extent; but, as is well known, even in its individual parts, which, as in the instance of the cervical and lumbar portions, become distinctly enlarged where they receive the great nerves of the thoracic and abdominal extremities. From the account which has been previously given, it is easy to understand the cause of this peculiar configuration; for it has been shown, that a considerable number of the fibres belonging to the spinal nerves do not go to the brain, but end in the grey matter of the cord; so that, in proportion as the nerves enlarge will be the number of the incident and reflex fibrils, and the consequent size of the spinal cord. But there is another circumstance requiring to be noticed: the grey substance being, as I conceive, the source of those independent and remarkable powers displayed by the cord, is necessarily proportioned to the size of the true spinal nerves, and is therefore accumulated in those places where these nerves are largest.

The anatomical characters of the invertebrated animals afford, however, the most striking evidence of the true formation of the spinal cord; and corroborate, in a manner not to be mistaken, the account that has been given in the preceding pages, of the anatomical arrangement of the spinal nerves. In the immense division of the articulata, it is found that the nerves of the body are attached to masses of a granular grey substance; but hitherto, the true relations existing on the one hand between the nerves and these masses, and on the other between the latter and what is considered as the brain,

have not been determined. A careful examination, however, of that descending, and, as it were, graduated scale, which is formed by the nervous system in the animal kingdom, unequivocally demonstrates that the articulata possess parts which are the exact analogues of the structures that exist in the vertebrata. It was surmised by Sir C. Bell, that there exists, from the worm up to man, a series of nerves subordinate to sensation and volition, constituting what that profound physiologist called the regular or symmetrical nerves; a supposition which has been in part realized by the beautiful discovery of Newport, who has proved the identity of the gangliated thread of the articulata, with the spinal cord of vertebral animals. This writer has not, it is true, referred to any division of the motor and sentient nerves into two orders of fibres, similar to those which are capable of demonstration in the vertebrata; nor have I been hitherto able to detect such an arrangement; but, when we consider the remarkable intricacy and minuteness of the whole structure in these animals, and recollect how lately even the two roots themselves have been discovered, it may be well permitted us to doubt if the entire anatomy of these nerves is yet known.

It is seen on inspection, that the nerves are attached, as has already been stated, to the ganglions, which bodies are themselves united together by a few delicate longitudinal threads, which also extend from the uppermost ganglion to the brain. Now, from the analogy of the vertebrated animals, it may be assumed that these threads consist, in part, of longitudinal commissures, by which the ganglia are combined in their functions; and in part of true sensiferous and volition filaments, which terminate in the brain. In descending the scale, from the most perfect animal to the lowest class in which a symmetrical

nervous system exists, it is seen, that, exactly as the motions of the body become independent of the brain, the nerves contain a larger proportion of those fibres (the true spinal) which terminate in the grey substance of the spinal cord, and fewer cerebral. But it is most erroneous to assert, as some authors have done,* that, "in the invertebrated animals, the spinal cord is not directly continuous either with the brain or with itself;" on the contrary, wherever there is a grey mass in the head, however minute, which *corresponds in office with the brain,* a connexion with the nerves, through the medium of the spinal cord, is indispensable to the exercise of that voluntary control over the motions of the body, which in these instances always exists.

In the invertebral animals thus endowed, there is in fact, no difference in the type of the cerebro-spinal axis when contrasted with that of the vertebrata; there are innumerable varieties of form, but in every instance the essential structures have a real existence.

These observations apply to those classes which possess an analogous organ to the brain, and which always evince a choice in the performance of their movements. But there are an immense number of the invertebrata in which no central cerebral organ can be dectected; but where, notwithstanding, a series of ganglia, united by threads and furnishing nerves, as in the star fish, are observed. These ganglions, and their associated nerves, seem to correspond rather to the true spinal cord, with its incident and reflex nerves, than to the brain; and yet, if there exist, as has been lately asserted, distinct organs of vision in the asteriæ, there must of necessity be a true cerebrum.

Again, there are other tribes, such as the polygastrica,

* Fletcher's Rud. of Phy. Pb. 2, b. p. 87.

the poriferæ, and the polypiferæ, in which there is no satisfactory evidence of the existence of any kind of nervous system. Although, under such circumstances, nothing positive can be advanced, I would yet observe it is probable, that if a distinct nervous structure should ever be discovered, it will be found to be analogous to the true spinal, and not to the cerebral system. It may be thought that this supposition is opposed by the circumstance that many of these animals, the polype for instance, in seizing its prey, are capable of executing what appear to be voluntary movements; but when the phenomena of the reflex action come to be investigated, it will be evident, that such motions may be effected without the agency either of sensation or volition.

The investigations, the principal results of which have been stated in this and the preceding chapter, confirm the opinion so generally entertained, that the spinal cord is something more than an appendage of the brain; that, in fact, it consists of two structures, not only distinct from each other by their anatomical characters, but, as will more clearly appear subsequently, endowed with totally independent properties. One of these structures consists of the grey matter, confined, it must be recollected, not merely to the vertebral portion of the cord, but extending into the cranium, as far as the striated bodies, the optic thalami, and the optic tubercles. Now it it has been shewn* that the grey substance, in general, is the source of the nervous power; and I believe it is further susceptible of proof, that the portion of that substance which is lodged in the spinal cord, is the source of the peculiar powers possessed by that organ; that, in fact, it constitutes, with the nervous fibres attached to it, the true

* See Chap. II.

spinal cord, the existence of which, as a structure independent of the brain, was first declared by Dr. M. Hall.

The second portion of the spinal cord consists of the white fibres, all of which, after a most complicated disposition, seem to extend to the convolutions of the cerebrum and the layers of the cerebellum; it may, therefore, with propriety be called the cerebral part of the cord.

The result of dissection further shows, that in the skin and all other sensitive surfaces to which the so called sentient nerves are distributed, there are, in reality, two orders of fibres essentially distinct from each other; one set terminating in the grey substance of the spinal cord, and the other in the white or cerebral fibres. In the same manner, with respect to the nerves distributed to the muscles, it is proved that each contains one class of fibres running into the grey matter of the cord, and another order ending in its cerebral portion.*

Thus, in the compound nerves of the body, there are in reality four instead of two different classes of fibres; and, when the physiology of these parts is considered, it will be made apparent, that these several fibres transmit different impressions: that of those going to the brain, the fibres derived from the sentient nerves, transmit impressions which excite sensation, and those belonging to the motor nerves, volition; that of the fibres attached to the grey matter of the cord, those derived from the sentient nerves, transmit impressions made on the skin to the true

* It is no argument against this statement, that these different orders of fibres cannot be demonstrated in the nervous cords going to the skin and the muscles. The same kind of objection applies to the existence of the sentient and motor fibrils in the compound nerves, which cannot be distinguished mechanically from each other; and yet no one doubts the justice of Sir C. Bell's conclusion as to their independence both in an anatomical and physiological point of view.

spinal cord, the peculiar power of which they excite; whilst those derived from the motor nerves, transmit to the muscles the effects of the power thus excited. Of these four classes, I conclude, that those attached to the grey matter are the incident and reflex nerves of Dr. Hall; and that they, together with that matter, constitute the true spinal or excito-motory system.

As, then, there exists, besides the nerves of sensation and volition, two other classes which are anatomically and physiologically distinct, it becomes necessary to distinguish these different orders by separate names.

Dr. M. Hall has proposed to call the fibres which pass from the skin to the true spinal cord, the *incident nerves*, and those which proceed from the true spinal cord to the muscles, the *reflex nerves*. These terms are very expressive of the powers, which these filaments probably possess, of transmitting impressions in the directions indicated by their names; and, therefore, may be with propriety adopted in treatises in which the excito-motory phenomena are considered. But, as at the present time, doubts still exist with respect to the exact mechanism by which the reflex action of the cord is effected, it is advisable to select, for general purposes, terms merely expressive of the facts which are established by the evidence of anatomy, and which do not involve any hypothetical doctrine. In this manner the nerves of the cerebro-spinal axis may be divided, as, indeed, Dr. Hall has proposed, into the true cerebral, comprising the true sentient and the true volition fibres; and the true spinal, consisting of those fibres derived from the anterior and posterior roots which enter the grey matter of the cord.

With these facts before us, the dispute respecting the existence of what are called the cerebral nerves, is readily determined. It is well known, that whilst such nerves

are admitted by some physiologists, the majority of writers in the present day contend, that all the nerves contained within the cranium, are spinal nerves. Neither of these opinions is correct; for each of the cranial nerves is, in reality, composed like those attached to the vertebral part of the spinal cord, of a true spinal and a true cerebral portion; the former being attached to the prolongation of the grey matter of the cord,* and the latter, to the sensiferous and volition fibres, which ascend to the grey matter of the cerebral convolutions. The only nerve which, perhaps, consists of cerebral fibrils alone, is the olfactory.

It is necessary, in conclusion, to point out a very important principle, in accordance with which the origin of the incident and reflex nerves is governed. From the office which has been assigned to the former, of transmitting the impressions of physical agents to the latter, it is evident that there must be, as Professor Müller has remarked, a ready means of communication between them. In obedience to this necessity, it is found that the central extremities of the incident nerves do, in reality, very closely approach the central extremities of those reflex nerves, with the function of which they are associated. This principle is very evident in all the spinal nerves, the incident and reflex fibres of which are attached to corresponding segments of the grey substance; and the same disposition is evinced in the incident and reflex fibres of the several cranial nerves, when they are traced with sufficient minuteness.

Mr. Mayo, whose valuable researches have thrown so much light on the reflex action of the spinal cord, has, with his usual acuteness, perceived the anatomical fact, but he has failed in detecting its physiological application.

* See p. 28.

He states, "I believe that the observation will be found to be correct, that nerves of motion take their rise from the same region or segment with those sentient nerves which transmit the impressions, by which their action is usually regulated."* Now the principle does not apply to the *sentient* but to the *incident* nerves; for the true sensiferous or cerebral fibres are not thus attached with the volition fibres of the motor nerve, to corresponding masses of the grey matter; on the contrary, the sensiferous fibres of the posterior roots, although for the convenience of arrangement they approach the volition fibres of the anterior roots in the spinal cord, yet they continue upwards till they reach the various convolutions of the brain; how far those two orders of fibres then approach each other, we have at present no means of ascertaining, nor does their disposition in the cerebrum concern the present question.

The explanation now offered of this fact affords a satisfactory elucidation of a principle which, otherwise, could not be comprehended; for, whatever assertions there may be to the contrary, it is certain that there is no necessary relation either between muscular contractility in general and sensibility, or between this latter property and the contraction of that portion of the muscular system, which is under the influence of volition. The eye may be directed, for example, by the will, towards any object we wish to view, without any previous impression having been made on the retina; and we certainly guide our steps, in general, without any reference to impressions made on the sentient nerves of the legs. But with respect to the reflex action of the spinal cord, the conditions are altogether different; for inasmuch as the reflex nerves are,

* Out. of Phy. p. 262.

in every case, without an exception, excited to action by the impressions of physical agents acting on the peripheral extremities of the incident nerves, it is evidently advantageous, though not absolutely indispensable, that the central ends of the two sets of conductors should approach each other.

CHAPTER IV.

PHYSIOLOGY OF THE SPINAL CORD.

THE prevailing opinions respecting the properties of this important part of the nervous system have been partly exposed in the first chapter. From what was there stated it is apparent, that the greatest uncertainty exists as to the share which this organ, inclusive of the medulla oblongata, bears in the exercise of sensation and volition. With the exceptions of Flourens, Sir C. Bell, and Dr. Hall, it is the received doctrine that the medulla oblongata, is essentially the seat of consciousness and volition; for it is asserted that those powers persist notwithstanding the want of the cerebral hemispheres, provided the cranial portion of the spinal cord be preserved intact; whilst the destruction of the medulla, the brain remaining entire, involves the loss of all feeling and the power of exciting the voluntary muscles. It must be acknowledged that the evidence upon which this hypothesis is supported, is of a character well calculated to enforce such a conclusion; and, although, in this chapter, facts will be adduced which it is conceived, are sufficient to prove the fallacy of most of those arguments on which the established doctrine rests; it is yet necessary to state, that owing to the difficulties attending this inquiry, some of which are, perhaps,

from its nature insurmountable, there will still remain some phenomena requiring further investigation.

It has been stated in an earlier part of this treatise, that the properties of the cranial portion of the spinal cord do not differ, excepting in degree, from those possessed by the vertebral part of the organ; but, as the question relating to the endowments of the former is greatly elucidated by the results of experiments performed on the latter; and inasmuch as many physiologists contend for a difference, not only of degree, but likewise of kind, it will be advantageous to consider in the first place the results of experiments performed upon the vertebral part, and, subsequently, to investigate the more complicated phenomena, which are connected with the medulla oblongata.

Of the vertebral portion of the Spinal Cord.—In every investigation respecting the endowments of the component parts of the nervous system, the withdrawal by the muscles of any portion of the body which has been cut off from its communication with the brain, consequent upon an irritation of the skin, has been assumed as a proof of the persistence of sensation and volition in the part thus irritated; and, so long as the integument was known to be furnished only with sentient nerves, and the muscles with nerves capable only of transmitting volition, it was impossible to admit any other explanation of the phenomenon in question. But when it has been proved by dissection, that all parts of the external surface are provided with two orders of nervous filaments, anatomically distinct from each other, and that a similar arrangement obtains in the voluntary muscles, the question assumes altogether a new character; for, with such an organization, there is no difficulty in understanding that impressions may be made on the skin which do not excite sensation,

and that contractions may be determined, in the voluntary muscles, without the agency of volition.

No physiologist has hitherto attempted any explanation of the cause of the subdivision of the nerves of sensation and of motion, each into a cerebral and spinal part; indeed, up to the present moment, the actual fact of this division has been doubted or denied. The structure, however, unquestionably exists; and, therefore, in all future discussions in which the anatomy of the nerves is involved, it will be necessary to investigate four instead of two roots in each compound spinal nerve.

The great principle established by Sir C. Bell, according to which each individual nervous fibre is endowed with a distinct property, tends to prove that the two orders of fibrils distributed to the skin, are connected with different functions. The most satisfactory mode of determining this point, would doubtless be to repeat, in this instance, the beautiful experiment of Sir C. Bell; and, by dividing the true spinal and the true cerebral fibres separately from each other, to ascertain the effects produced. This is an experiment, however, which, in consequence of the anatomical relations, cannot be performed; but, by cutting the spinal cord across, we divide the cerebral fibres, whilst, as will be seen by a reference to the plan, *(See pl.* 1. *fig.* 3.*)* the true spinal fibres, with the grey matter to which they are attached, remain entire; in this manner a separation is effected between the two orders of fibres, which is impracticable by any other means. This is, in fact, the experiment which has been so often performed in living animals, in every one of which instances it is known, that the cord still retains the power of exciting the voluntary muscles when impressions are made on the skin. The point to be determined is the nature of this inherent power of reflecting impressions. Is it volition, or, is it some other and distinct property?

The phenomenon is so highly important, and bears so immediately upon the question at issue respecting the true seat of sensation, that I have repeated the experiment, very frequently, with various modifications, and in various animals: the following are the results that have been obtained.

Expt. 1.—In a rabbit, about three parts grown, the cord was laid bare in the middle of the back, and a portion of it cut out. The lower part of the body, and the hind legs, were immediately paralysed; the limbs were laid motionless on the table, and the animal had no power of moving them; a fact which became very striking when the rabbit made an attempt to walk; for then, notwithstanding the fore legs freely acted, and thus dragged along the body, the hind legs were motionless; volition, although in full operation, had no effect upon them. I then, with a fine needle, pricked the skin covering the under part of the heel, when, instantly, *the toes became extended, the heel was raised, and both legs were forcibly thrown backwards.* This experiment was repeated on several other rabbits, in kittens, and in puppies, and constantly with the same result; the combined and successive motions of the toes, the foot, and the leg, were seen; but in the kitten, the irritation to produce the effect required to be made, not on the heel, as in the rabbit, but nearer the toes. In most of these instances, it was also found that only the leg belonging to the foot which was irritated, was thrown backwards.

Expt. 2.—In a similar experiment performed by Mr. Mayo,* it is stated that when the foot was irritated, the movement of the limb was exactly similar to that which the animal would make, if in indisputed possession of its sensation. In order to ascertain the correctness of this statement, I pricked the hind foot in a rabbit, the cord of

* See p. 7. of this Treatise.

which was entire, when the animal moved the limb to avoid the irritation; but the motion was totally different from that which occurred in the preceding experiment. Upon dividing the cord and pricking the under part of the foot, most violent motion was excited, and both legs were thrown back. Those gentlemen who were present, were particularly struck with the difference of the movements in this rabbit, before and after the division of the spinal cord. I found in this, and other similar experiments, that when the thin skin of the leg was touched after the section of the cord, a very slight contraction was produced; and that it was only when the *under part of the foot*, which in progression strikes on the ground, was irritated, that the remarkable and combined action of both legs was produced.

Expt. 3.—In consequence of the great activity of the spinal cord, in very young vertebral animals, when it is divided most violent actions are frequently observed in the hind legs, without the skin being irritated; and, as these, like all the motions produced by the cord, are combined, they are liable to be mistaken for voluntary movements. The following experiment shows the real nature of these contractions. A portion of the cord was removed in the middle of the back, in a very young rabbit; on pricking the foot, the same kind of movements as in the former instances were excited; in consequence of the activity of the cord at this early age, the effects, however, were proportionably much more marked than in the adult animal. But the peculiar fact noticed was, that from time to time, without any stimulus being applied, the hind legs were forcibly and repeatedly thrown back, as if the animal was running quickly; whilst at these times, the fore limbs, which were still under the controul of the animal, remained motionless. These movements were so decided and long-continued, that it would have

been difficult to have rejected the idea of sensation and volition still remaining in the hinder part of the body, if it had not been distinctly observed, that, when the same animal attempted to walk, it could only move the two fore legs; by whose power, the hinder ones, and the trunk below the division of the cord, which were perfectly motionless, were dragged along the table. It is necessary to bear these facts in mind, because they afford a clue to a class of movements which become much more palpable in insects, &c.; in which animals it is not possible to obtain the same kind of evidence as to their real nature. It is probable that the motions in this and similar instances, result from the irritation which the cord experiences, when it is cut through; or they may in part be produced by loss of blood.

In cold blooded animals, in consequence of the great proportional size of the spinal cord, it is well known that after decapitation, the body retains for a long time the capability of being excited to produce motions; so much so, indeed, that in serpents, lizards, frogs, &c. it has been very generally supposed that the sensorium, or seat of sensation and volition, becomes more diffused, as it were, than in the concentrated organs of birds and mammalia; so that "the spinal cord partakes with the brain in all its faculties."* In consequence of this great tenacity, the amphibia are particularly favourable for the investigation of the reflex action of the spinal cord; and, in this respect, the salamander (*salamandra maculata*) is admirably adapted for the purposes of the physiologist. The excito-motory phenomena in this animal are in fact so extraordinary, they simulate in such a wonderful manner the results of sensation and volition, that it is most difficult for the mind, influenced as it is by the received doctrines of phy-

* Bostock El. Sys. of Phy. p. 152.

siology, to conceive that such actions can occur in parts utterly deprived of all consciousness. I availed myself of a residence of several weeks at Heidelberg, where this animal abounds, very cautiously to analyze the effects of dividing the spinal cord; especially, in reference to the persistence of sensation in the parts thus cut off from the brain.

Expt. 4.—The body of a salamander was cut into two pieces, so that the pelvis with the hind legs and tail attached to it, was entirely separated; and the phenomena of the reflex power were carefully noticed. Some convulsive motions of the legs and tail, as in all other instances, took place. Upon pricking the feet the limbs were freely moved, and also the tail; and from the application of one stimulus, the motions were several times repeated in consequence of the limbs at each movement coming in contact with the table. The effect of applying great heat, a piece of lighted paper for instance, was yet more remarkable; for, upon touching one of the legs or tail, the pelvis and tail were forcibly moved; those parts seemed in fact to be writhing under the excess of suffering. In this case, as in every other in which the reflex action is excited, it was found that the extent of motion depended on the intensity of the stimulus; a combination of circumstances than which it is scarcely possible to conceive any more decisive proof, that feeling still remained; in fact, without some powerful evidence to the contrary, no other conclusion could be formed.

Expt. 5.—In another salamander the spinal cord was simply divided, without any further injury being inflicted. Upon pricking the foot and tail the same motions were produced as in the former experiment; and upon applying a lighted paper, violent movements were excited in the tail and legs. All this seemed to indicate the persistence

of sensation and volition; and yet it was found that the limbs, which could be so violently excited by mechanical irritation and by heat, remained motionless under the impulse of the will; so that when the creature made an effort to walk, which it frequently attempted, the hind legs and tail were, as in the case of the rabbit, kitten, &c. dragged along completely paralysed. Now, as the very idea of volition implies a perfect control over any muscle which an animal may wish to stimulate, this utter want of such power, is the most decisive proof which could be adduced, to show that in this and similar cases, the empire of the will was destroyed by the section of the spinal cord. But it may be thought that, although under these circumstances there was no longer any volition, sensation might still remain; a supposition, however, inconsistent with the fact that, in this same salamander, I found by proceeding cautiously, so that the animal could not see the approach of the hand, that an entire hind leg could be cut off with a pair of scissors, without the creature moving or giving any other expression of suffering.

Expt. 6.—In a frog half grown, the spinal cord was divided in the back; the hind legs were immediately paralysed, a fact rendered the more striking because the animal made violent efforts to walk, the head being raised up and the fore legs freely moved; during all these struggles the hind legs remained perfectly motionless. Upon applying a lighted paper to one of the hind legs a distinct motion was excited, and simultaneously, as if by an electric shock, the opposite leg was also similarly affected; the approach only of the paper without actual contact, was productive of the same effect, but in a less degree. The hind leg was then cut off without the animal attempting the least motion. The head was afterwards removed, when similar actions, only more violent, were excited in

the anterior extremities. In this instance there was a beautiful illustration of the transmission of an impression from one side of the body to the other by the spinal cord; an effect, however, quite different from any voluntary act; for when a part of a limb is burnt in a perfect animal, the limb only which is injured is retracted; the two together are never thus moved. This experiment was repeated in several other salamanders and frogs, and always with the same results.

Expt. 7.—Dr. Hall has pointed out the extraordinary susceptibility of the verge of the anus, in producing the reflex action of the cord; and I have myself remarked the same thing in every species of animal—in mammalia,—in amphibia, and in insects. In connexion with this fact it is important to describe a phenomenon, which was noticed by Professor Bischoff in the green frog (*Rana arborea)* so common in many parts of Germany. Upon irritating the cloaca in one of these animals which had been decapitated, the most violent motions were excited in the hind legs, and *repeated attempts were made by these limbs to remove the instrument,* with which the cloaca was touched. This fact I have since repeatedly seen, in the green and common frog, both when the head was removed* and when the spinal cord was divided in the back; the same thing may readily be noticed in the common fly and other insects, after decapitation. I have also observed that if, after having cut off the head in frogs, fire is applied to the fore part of the trunk, violent motions to remove the source of excitement are made. It is impossible not to be struck with the analogy of this curious phenomenon, occurring, it must be remembered, when it can be proved

* It is necessary in batrachian reptiles to be very careful in removing the head, that the section is made sufficiently low, or otherwise a part of the brain remains attached to the body.

that sensation and volition were destroyed, and the experiments of Magendie; in which, after the removal of the cerebrum and cerebellum, the animal employed its feet to remove a source of irritation from the face, caused either by plucking a hair of the whisker, or by dropping concentrated acid on the nose.*

In these experiments, it was found that when the surface of the body was touched, as in the case of decapitated serpents, the headless trunk of the salamander was constantly turned in the direction of the irritation; and that, when both sides of the trunk were simultaneously pinched, the body made violent movements, which, if the head remained attached, would be called struggles. It is likewise particularly worthy of observation, that in frogs there is a marked difference in the degree of excitability in the anterior and posterior limbs, after decapitation; the latter which are almost exclusively employed in swimming, displaying, when pricked, more forcible movements than the former.

It is necessary to remark that there is observed a great difference in different animals as to the effects of dividing the cord. In some, the excitability of the limb is much greater than in others of the same kind; amongst frogs for instance, there is a great variety in this respect; this appears greatly to depend, cæteris paribus, on the degree of mischief to other parts, which accompanies the section, and especially on the quantity of blood that is lost. When it is known how seriously the functions of the brain are impaired by the loss of a small quantity of blood, taken from the general system; that the sudden removal of a pint for instance, will for a time annihilate the true cerebral action by causing syncope, it is not surprising that a

* The motions above noticed, are best seen when the cord is divided high up towards the neck.

sudden loss of a few drops of blood, some of which come directly from the arteries of the cord, should, in a frog, greatly weaken, or even, as sometimes happens, quite destroy the reflex action. It is also proper to remark that the division of the cord, inflicting as it does the highest possible degree of mechanical injury, without an utter destruction of the substance of the organ, is usually, for a time, followed by a total loss of the true spinal function; so that it is necessary to wait, occasionally even a considerable time, before the excito-motory action can be observed.

We may in the next place consider the evidence afforded by the articulated animals. It is certain from recent investigations, that in the numerous classes of this great division of the animal kingdom, there exists a nervous system analogous in its essential structures to the cerebro-spinal system of the vertebrata. This important discovery gives increased value to the observations of the excito-motory actions which are displayed in these animals; and which phenomena become so much the more striking, in consequence of the brain, as we are justified in regarding the masses contained in the head, having attained proportionably to the spinal cord, apparently its minimum size. With such a conformation, if the theory of the reflex action of the cord be really founded in truth, the removal of the head ought to be productive of the most remarkable effects. Experiments entirely corroborate the deduction drawn from the anatomical structure. If the head be taken off from a common fly, the body, like the frog under similar circumstances, maintains its natural position; but, notwithstanding this, it usually happens that there are twitchings of the limbs, and the wings may move with rapidity without any external application, in consequence, most probably, of the severe irritation caused

by the division of the cord. Combined motions of the legs, especially of the hinder pair, are under such circumstances observed; they are not, however, voluntary, but similar to those described in the third experiment. If the legs be touched they not only freely move, but the wings, also, are often set in full action, a phenomenon which is referable to the combination of the several ganglia by the connecting or commissural threads. It oftens happens, especially if a large fly be selected, that after the loss of the head, the body is moved freely by the wings whenever it is touched; in fact flying is performed. Although the power of attaching itself by the feet, is considerably weakened, yet, it in part remains; so that, frequently, the body is supported in opposition to gravity by two or three of the feet becoming fixed to the surface which they touch.*

* It had occurred to me that in this and all similar contrivances, such as the suckers of the cephalopoda, &c., that these parts act altogether independently of volition; the mere contact of any substance being, in fact, sufficient to excite the required motions. This opinion is supported, not only by what has been stated above respecting flies, but more especially by some interesting phenomena that I have noticed in the hyla, or tree frog. It is the common opinion, that this animal "supports itself among the leaves of the trees in which it lives, by the clammy slime by which it is covered." (Blumenbach, El. of Nat. Hist. translated by R. T. Gore, p. 138.) The correctness of this explanation is very doubtful. In many examinations of these animals, whilst alive and in health, I have never perceived more slimy matter than in other frogs; but the hyla possesses a remarkable apparatus, consisting of a rounded bulb, at the end of each toe; by which, in ascending a smooth surface, as a glass, it is evident the feet become attached, and by which some resistance is caused when the animal is taken up by the hand. The exact structure of these bulbs I have not had an opportunity of examining; and I have not been able to obtain any information on the subject from some of the first comparative anatomists of England and Germany; it is most probable, however, that they are suckers. Whatever may be the mechanism, I noticed, in one instance, that it may be excited to action after the division of the cord; and an intelligent student, Mr. Bensbach of Heidelberg, who at my request divided the cord in another of these frogs, writes, that "after the division of the cord, on

The mole cricket (gryllotalpa vulgaris) exhibits very remarkable powers of motion, after the removal of the head; upon being excited, the limbs are freely moved, and, under these circumstances, it often walks a considerable distance; a fact which is very interesting in relation to the mode in which locomotion may be excited, by the impressions arising from the feet coming in contact with the ground.

In experimenting upon insects, it is observed that all parts of the external surface are not equally susceptible of being excited; but that, as in the rabbit, the frog, &c., the portions of the limbs which in progression strike the ground are always, when irritated, productive of the most energetic motion. In this manner it is found that, upon strongly pinching the extremity of a foot, the whole of the limbs are violently excited; whilst, if other parts are touched, the effect is often inconsiderable.

The results obtained by experiments performed on the articulata, are, when carefully considered, found to correspond in character with those obtained by vivisections practised on the vertebrata; the only difference relating to the extent of the reflex action. In both cases there is the same absence of all spontaneous motion, in the parts cut off from their connexion with the brain; the same convulsive motions arising from time to time, without any external irritation; the same kind of combined motion, when the surface is stimulated; and the same modification in the intensity of the excited actions, according to the part upon which the impression is made. Thus, the

placing the foot on one of his fingers, he *felt* the toes becoming attached." Mr. Owen informs me that in the gecko there is a sort of sucker apparatus; and in a fly, *(sarcophaga carnaria,)* which possesses a circular disk, at the end of each foot, I have observed that the power of retaining its hold is much greater, after decapitation, than in insects wanting such a structure.

investigations of physiology are in harmony with the discoveries of anatomy; and both tend to illustrate that uniformity of structure and function which is one of the most essential, and at the same time interesting phenomena, displayed in the organic world.

Of the cranial portions of the spinal cord, or medulla oblongata.—This division of the spinal structure, which comprises not only the medulla oblongata, but also the prolongation of it constituting the crura cerebri, the optic tubercles, and the fibrous, and perhaps even the grey matter of the optic thalami, has always been considered as a highly important organ; and, in consequence of the extraordinary and unexpected effects that have resulted from the investigations of modern experimentalists, it has happened that this structure is at the present time regarded, as being more essential to the support of life, and even of those operations which are the special endowments of the animal kingdom, than the brain itself. That the medulla oblongata is indispensable to the manifestation of some of those functions belonging to the organic life, by which extra-uterine existence is supported, is an axiom proved by incontrovertible evidence: it is, for example, essential to the performance of those motions by which two acts necessary to digestion, sucking and deglutition, are accomplished; and it is further essential to the performance of the movements of the diaphragm, by the agency of which another organic function, respiration, is effected. But, notwithstanding that the agency of this organ is thus evinced, in two of the most important of the vital functions, no physiologist, with the exception of Dr. Hall, has been able to detect in what that agency consists.

The medulla oblongata, in addition to its relation to

the organic functions, is also supposed, according to the received doctrines of physiology, to be the seat of sensation and volition. This position has not, however, obtained universal assent; it has, in fact, been admitted, not on account of any sufficiency of the proofs on which it is based, but because no other more satisfactory explanation had, until the principle of the reflex action was discovered, been advanced.

In its anatomical characters, the medulla oblongata presents a more intricate structure than the other part of the spinal cord; but the difference appears to be one rather of degree than of kind, consisting, especially, in the greater accumulation of grey matter. The fibrous part, also, is more complicated, a circumstance which is probably altogether subordinate to the due arrangement of the different classes of fibres, preparatory to their peculiar distribution to the cerebrum and cerebellum; for, it must be recollected that the projecting bodies seen on its surface are not proper to it; but are, like the fibrous part of the cord, appendages of the brain; to the action of which organ, and not of the oblong medulla itself, they are subordinate. In investigating, then, the properties of this part of the cord, we must avoid attributing to it peculiarities of structure, which, probably, it does not in reality possess.

The investigation of the endowments of the medulla oblongata may be prosecuted with the greatest advantage, by considering, first, the effects of vivisections performed on the brain; secondly, the true nature of the phenomena displayed by anencephalous infants; thirdly, the evidence afforded by pathology.

1. *Effects of vivisections performed on the brain.*—The researches of those experimentalists who have endeavoured to determine the functions of the several parts of the

encephalon, by mutilation practised on living animals, are immediately connected with the subject of the present inquiry. It is, indeed, apparent that the whole question concerning the truth or falsehood of the theory, which attributes the reflex power to the spinal cord, hinges upon the correctness or incorrectness of the received doctrines respecting the seat of sensation and volition; so that, until those doctrines are proved to be false, it is impossible to establish the hypothesis of Dr. Hall; for, as the inquiry stands at present, the two theories are utterly irreconcilable. As so much importance, then, attaches to these vivisections, it becomes necessary to submit them to a most searching investigation.

Among these experiments, the most celebrated, and those from which the most essential conclusions have been deduced, are those of M. M. Flourens, Magendie, and Desmoulins. The inquiries of the former writer are stamped with the characters of truth; and are calculated, in a most powerful degree, to obviate the difficulties in which this, the prime question of physiology, is still involved. It will be presently shown, how minutely the facts stated by M. Flourens accord with the results of the experiments related in the preceding pages; but then there was a clue wanting; and which being absent, the deductions of this enlightened physiologist, although accurately correct, could never be satisfactorily established.* The consequence has been, that these identical experiments have been one of the principal foundations for the opinion so generally entertained, that the cerebral hemispheres are not essential to sensation and volition.

The important and untiring labours of M. Magendie, in

* I allude to the conclusions of M. Flourens respecting the seat of sensation and volition; some of his other deductions, especially those concerning the functions of the cerebellum, appear to be erroneous.

the field of physiological science, justly entitle him to the respect of all who are anxious for the successful cultivation of that interesting branch of knowledge. Imbued with this feeling, I approach his labours connected with the nervous system with much regret; because I feel myself compelled to state, that, so far from admitting that they tend to remove the veil which obscures the operations of the brain, I conceive that, viewed in the aggregate, they have constituted the great barrier to the progress of modern physiology. In stating this opinion, I only give expression to a sentiment entertained by some of the most profound physiologists of Europe; who perceive that the doctrines advocated by systematic writers, and which have mainly originated in the researches of M. Magendie, are totally insufficient to explain the phenomena of muscular action, and are, in many respects, contradictory of each other. It is acknowledged by all parties, that the results of vivisections, particularly those which relate to the mental operations of animals, in which it is so difficult justly to interpret the effects produced on their feelings, must be received with the greatest caution. There are, in fact, difficulties inseparable from such investigations, in whatever manner they may be conducted; but these difficulties are immeasurably increased when experiments are performed on living animals, not to test the correctness of opinions founded on an antecedent process of reasoning; but to open, as it were, the chapter of accidents, and to endeavour, by a lucky chance, to discover something new. In this respect, the method pursued by M. Magendie is most objectionable; as it is apparent that his mutilations were practised with no definite object, but with the design of wresting from their results, some conclusions respecting the most mysterious phenomena of the animal frame. But nature is not thus to be forced

into a disclosure of her hidden truths; success, when it is to be obtained by experimental inquiry, which when judiciously applied is a very important means of discovery, can only be commanded, by making these manual operations subservient to comprehensive views of the laws which regulate the structure and functions of organized bodies. Such being the unphilosophic spirit in which these experiments were conducted, we are justified in viewing with doubt the conclusions they are supposed to warrant; especially when it is recollected, that, in the same work in which they are related, doubts are expressed whether the olfactory is the nerve of smell, the optic the nerve of vision, or the auditory the nerve of hearing.

I proceed to consider these experiments, as far as they relate to the properties of the medulla oblongata.

The inquiries of M. Flourens induced that excellent physiologist to conclude, that the cerebral lobes are the exclusive seat of perception, sensation, and volition; but so strong is the apparent testimony of an opposite nature, that, excepting Sir C. Bell* and Dr. Hall, not a single physiologist has admitted this conclusion; the prevailing opinion mainly supported by these identical experiments being, that consciousness and volition are attributes of the medulla oblongata. As these researches have exerted so great an influence on the modern doctrines of physiology, no apology is necessary for presenting a brief account of the celebrated experiment from which, principally, such contradictory conclusions have been drawn.†

* I regret that the first chapter of this work was printed before I was aware of the opinion of Sir C. Bell, relative to the seat of sensation and volition; as the weight attaching to such authority, must powerfully support the views I am advocating.

† This epitome, which is a faithful abstract from the original work, is extracted from the very interesting treatise of Mr. Solly, on the human brain, (p. 310.)

"M. Flourens removed, at the same time, the two cerebral lobes of a healthy chicken.

"The animal, thus deprived of its cerebrum, survived ten whole months in a state of perfect health, and would in all probability have lived longer, if M. Flourens had not been obliged to leave Paris.

"During the whole of this time, M. Flourens closely watched all the actions, habits, &c. of the animal; and the following is the result of his observations:

"He had scarcely removed the brain, before the sight of both eyes was suddenly lost; the hearing was also gone, and the animal did not give the slightest sign of volition, but kept himself perfectly upright upon his legs, and walked when he was irritated, or when he was pushed; when thrown into the air he flew, and swallowed water when it was poured into his beak.

"He never moved, unless he was irritated; when placed upon his feet he remained upon them; when seated on his belly, in the manner that chickens do when they sleep, he appeared plunged in a sort of drowsiness, which neither sound nor light in the slightest degree disturbed; nothing but direct irritation, such as pinching, or pricking, or striking, had any effect in rousing him.

"When the animal did move about, it seemed to do so without any motive or object; though there were no convulsions, nor any want of harmony in its movements; if it met with any obstruction, it did not know how to avoid it.

"The chicken was quite healthy; and five months after the operation the wound had quite healed, and a new layer of bony matter was forming.

"Still, it had no sense of smell or taste; neither had it any sensation of hunger or thirst; for, after allowing it to fast for three whole days, and then placing food immedi-

ately under its nostrils, and afterwards putting it into his beak, and also putting its beak into water, it did not show the slightest disposition either to eat or drink; and would have died for want of nourishment, if it had not been fed by force.

"It seemed entirely to have lost its memory; for, if it struck itself against any body, it would not avoid it, but repeat the blow immediately."

Nothing can be more interesting than these details; and, when viewed in connexion with the experiments related in the preceding pages, in which the cord was divided, they cannot fail of throwing considerable light on the true functions of the medulla oblongata.

We learn, that the removal of the brain caused an immediate loss of the senses of vision and hearing; that the sensations of hunger and thirst were destroyed; that the animal never moved, unless it was irritated; and that it was plunged in a state of stupor, or sleep. But, then, this bird moved when it was irritated, although without motive or object; it flew, when tossed in the air; it swallowed water, when poured into the beak; and respiration was still carried on: and these are, by the opponents of Flourens, received as sufficient proofs of the persistence of consciousness, sensation, and volition. It is admitted, however, that sensation, as far as vision and hearing are concerned, was destroyed; and the only evidence of the sensation of the external surface and consciousness remaining, is the fact, that the animal moved when it was touched; and flew, when thrown in the air. But it has been shown,* that the mere occurrence of movements, in a part of the body cut off from connexion with the brain, consequent upon the irritation of the skin, is no proof of sensation remaining; and, also, that the combined motions

* See Expts. 5 and 6.

necessary to progression, can be excited in a rabbit, by touching the integument, under circumstances in which it was certain that volition was destroyed. In decapitated insects, in which, for reasons already assigned, it must be supposed all feeling and will are lost; it was yet found, that walking and flying could be excited, by touching the limbs. The chicken, in this most interesting experiment, was, in fact, precisely in the same state as the insect without its head, and the salamander with the spinal cord divided; except that it presented those functions in addition, deglutition and breathing, which are dependent on the medulla oblongata; indeed, if M. Flourens had been fully acquainted with the principles of the reflex action, he could not have drawn up a more exact history of the excito-motory phenomena, as contra-distinguished from the operations of sensation and volition.

The power of swallowing and breathing, which remains under the above circumstances, may be more conveniently considered, in connexion with the same actions of anencephalous infants.

The observations of M. Flourens, respecting the optic tubercles, are extremely valuable. He found that the operation of removing these bodies was always attended with convulsions, and, when both were taken away, with complete blindness. The loss of vision is owing to the cause so accurately expressed by Flourens; for "the optic tubercle is, as regards vision, only a conductor; the cerebral lobe alone is the limit of sensation, and the place where it is consummated, by being converted into perception."* As regards the convulsions attending the injury of these bodies, as the optic tubercles form a part of the spinal cord, it happens, in the same manner as when the cord itself is irritated, that convulsions are

* Recher. Exper. p. 80.

necessarily produced, when those bodies are pricked, or otherwise injured.

But another circumstance of great interest, both in a physiological and pathological point of view, requires to be noticed, in connexion with this subject. We learn, from the interesting experiment of Mr. Mayo,* that the optic nerve, when pinched, excites the actions of the iris, although the brain is removed. Now, we have here the exact type of the whole excito-motory phenomena, and under circumstances which admit of no dispute; that is to say, the impression of a physical agent on a nerve of sense, exciting actions in the associated muscle, (the iris,) when all sensation, as far as the organ implicated is concerned, is allowed to be destroyed.

We learn, from this experiment, that the optic nerve not only has the capability of transmitting the impressions of light, by which vision is produced; but, also, *the effects of mechanical irritation*, by which contractions of the iris are excited. These facts are known, but the manner in which they are accomplished has not, hitherto, been explained; nor was such an explanation possible, until the true anatomy of the nerves had been discovered. The truth is, that the optic nerve, like the common sentient nerves of the skin, contains two orders of fibres; the true sensiferous, which are connected with the cerebral convolutions, by the diverging fibres described by Spurzheim, and the incident fibres attached either to the grey matter of the optic tubercles, or of the optic thalami. It is not possible to speak, with certainty, on this latter point; because the actual distinction in the use of the tubercles and thalami has never been determined by experiment; but, as Flourens remarks that the loss of the former does

* See p. 4.

not destroy the motions of the iris, the incident fibres are probably connected with the latter. Now those impressions made on the retina, which produce vision, are, it is certain, transmitted by the true sensiferous fibres to the cerebral convolutions; for, as Flourens has proved, the loss of the hemisphere, the other parts remaining intact, destroys in the animal the power of seeing; whilst it is as certain, from the experiment of Mr. Mayo, that the impressions, which excite the actions of the iris, are transmitted by those fibres which go either to the optic tubercles, or to the thalami.

It is thus, then, proved that the retina transmits two different kinds of impressions; and it becomes interesting to know how they are excited, in the normal state of the body. Explanatory of this phenomena, the following suggestion may be offered. The beautiful discovery by Herschel, shows, that solar light contains, besides the luminous rays, calorific rays, which are invisible; so that the light which reaches the eye is composed of two different physical agents, each of which is, doubtless, destined to exert its appropriate influence. Now, it is in perfect accordance with the extraordinary power, which it has been shown that heat possesses, of exciting the reflex action of the spinal cord, to conclude that the luminous rays exert their influence on the cerebral hemispheres, which is, indeed, proved by direct experiments; and that the calorific excite the incident and reflex fibres of the optic and oculo-muscular nerves; and so induce that preservative action of the iris, which is essential to the protection of the retina.*

* I have not thought it necessary to allude to the existence of those rays which exert a chemical influence; nor to the magnetising power, imagined by some writers to be possessed by the spectrum; the former can scarcely be

The existence of two orders of conductors existing in the optic nerve, and transmitting impressions either to the brain or to the optic tubercles (or thalami), offers also a clue to those apparent anomalies in the state of the pupil, which are so often observed in injuries of the brain producing coma, in apoplexy, and in amaurosis. In these affections, in all of which there is total blindness, the pupil is sometimes immoveable, whilst at other times it readily acts under the stimulus of light; and all this occurs, as if there were no fixed laws regulating the actions of the iris. But if a series of observations were instituted, to determine these and other phenomena connected with the reflex action of the spinal cord, and such an inquiry would be of great interest, it would, doubtless, be determined that, when in compression of the brain, the iris retains its power although there is a loss of vision, the cause of compression is confined to the percipient organs, the cerebral hemispheres; and that when there is both a state of blindness and a fixed pupil, the mischief implicates the optic tubercles and thalami, as well as the hemispheres. The same remarks apply to cases of amaurosis depending on disease of the brain. Of course in all these cases, if the trunk of the nerve or retina is injured or diseased, the pupil will be fixed.

The general results of the experiments of M. M. Magendie and Desmoulins, may be summed up as follows: "If, after having opened the cranium, all the parts of the cerebrum, the optic lobes, and the entire cerebellum are cut away in succession from before, backwards, in such a manner that the last cut is made above the attachment of the fifth pair, the animal continues to have the con-

supposed to exert any influence in the present instance; and the latter doctrine, although it would be of interest if true, has latterly been called in question.

sciousness of all the impressions which have their seat in the face, excepting that of sight. It continues, also, to be as vividly affected by sounds, odours, sapid substances, and punctures of the face, as if it experienced no other inconvenience than that which results from the mere loss of blood caused by opening the cranium; further, the animal cries, if, by example, a hair of its whisker be plucked, or if a strong acid be applied to the nose; lastly, the animal endeavours with its paws, to remove any source of irritation, as it would do if it had not been mutilated"*

That these are most extraordinary phenomena will readily be granted; and at the time when no other mode of exciting the voluntary muscles was known, than through the medium of the will; it was difficult to account for the active and combined motions above related, without admitting the agency of sensation and volition. It was this consideration which led to the belief, that these faculties operated by means of the medulla oblongata; a conclusion, in which I formerly participated, although not without perceiving that it was quite insufficient to explain the actions of the nervous system.

After what has been said in reference to the experiments of Flourens, it is only necessary to notice two of the above phenomena; the attempts, namely, made by the paws to remove a source of irritation, and the cries uttered by the animal. It certainly would at first appear that no two circumstances could be adduced, which tend more plainly to evince pain and suffering than those just mentioned.

But it has been shown,† that the most remarkable movements and contortions are caused by applications, that of fire for example, which are known in a perfect animal to excite the most acute pain; and yet that these

* Anat. des Sys. Nerv. p. 560.

† See Experiments 5 and 6.

actions take place in parts, which are proved to possess neither sensation nor volition. The effect of irritating the cloaca in frogs, under circumstances in which feeling and the will were shown not to exist is, however, more in point;* for it exhibits motions that are the very counterpart of those which are seen in animals experimentally deprived of their brain; in both instances the limbs were used to remove a source of irritation. It will, doubtless, seem almost incredible that such apparently intelligent actions, should be effected without the agency of perception; but there is a power inherent in the true spinal cord, which is invariably excited by the application of a physical agent, and that independently of sensation and volition, capable of producing motions as intricate in their combinations, and tending to as definite an object, as any which are the undoubted and immediate results of consciousness. There are for example, no actions in the body more complex in their character, or requiring the combined contraction of a greater number of muscles, than those which effect deglutition; and yet evidence will be adduced when that process is considered, which will show in a manner not to be controverted, that this function, the result of a physical impression, is not of necessity attended with sensation, and is never effected by volition.

In the whole of the effects described in the experiment under consideration, there is none more difficult to explain, without admitting the interposition of consciousness, than the power of uttering cries; which, as we have seen, still remains after the ablation of the brain, and, also, in anencephalous infants. To attempt an explanation with any chance of success, it is necessary to abandon all preconceived notions, as to the real character of this pheno-

* See Experiment. 7.

menon. There is the greatest reason to conclude, not only that the actions observed in anencephalous infants, which have for a time maintained extra-uterine life, are, altogether the results of excited motions; but that *all* the acts of *every* new born infant, as will subsequently be stated, are for a brief period, entirely dependent on the reflex power of the spinal cord. The sound of crying it must be further remembered, is nothing but a mechanical effect; it is, also, one of the phenomena of respiration, a process which is unquestionably capable of being effected without the agency of sensation and volition; and, although it is true there are many other functions, such as voice and speech, equally connected with the respiratory process, which are purely the effects of volition; yet it is quite consistent with the character of the excited movements in general, to conclude that this particular action, crying, is excited, and not voluntary. For, as it has been proved, that the application of fire to the skin excites violent motions when no sensation exists, it may in the same manner be concluded, that the exposure of the surface of the new born animal to the stimulating effect of the atmosphere, and to the impressions of various surrounding bodies, may induce that particular combination of the respiratory muscles, by which the sound of crying is produced, without the agency of feeling.* The essential object of this cry or vagitus, is not to express a painful, but an injurious impression, and in this manner to attract the notice of the mother, whose ever watchful care is the substitute beneficently provided by the Creator, for that total absence of self protection, so conspicuous in those new born animals, in which the vagitus is observed.

* The first act of the new born infant is to make an inspiration, doubtless from the contact of the atmosphere; the second, to utter cries, equally the result of atmospheric, and other external contact.

But it, also, is the sign by which the want of food is expressed; and, although hunger is, undoubtedly, a true sensation, yet, it may be supposed that a physical impression is made on the vagus nerve by the empty state of the stomach, which excites the action of the diaphragm and respiratory muscles, without the intervention of sensation; in the same way as the branches of that nerve where it supplies the lungs, do unquestionably excite the same muscles without any feeling being produced. The following facts, which I have ascertained by inquiry from the attendants of a large lying-in hospital, and other sources, are worthy of notice, as corroborative of the explanation here offered as to the true character of the vagitus. Generally, as soon as the young infant wakes, it cries; not, it is evident, because it is in pain, but because it wants food; and this is the interpretation of mothers, for they do not regard this crying as an indication of suffering. It is, also, very interesting that the vagitus is not accompanied with the shedding of tears; but when the infant begins to notice surrounding objects, then the crying is attended with lachrymation. All this is only seen shortly after birth, and the younger the infant, the more strongly do the phenomena occur. Very soon, when the mind begins to act, the character of crying is changed; it is *then* accompanied by tears; is evidently connected with a mental act, and is associated with painful impressions, or even by unpleasant emotions; so that, although at first the infant may be passed from the hands of one person to those of another without exciting crying, yet, after a short time, if a stranger takes it, the infant cries, evidently from a mental emotion. In this manner it is possible to understand that cries may be excited in animals deprived of their brain, without the operation of true sensation and volition. But this subject requires much careful investi-

gation; and most valuable information would result from a carefully conducted series of observations, on the phenomena of new born animals, especially of the human infant.

In considering the phenomena displayed in anencephalous infants, there will arise an occasion to refer again to some of the preceding experiments. I shall, therefore, merely add, in concluding this part of the inquiry, that, although in some few experiments which I have performed on pigeons, in which the brain was removed, the effects were not so strongly marked as in those above related; yet there is no reason to doubt the reality of the results obtained by Flourens, Magendie, and Desmoulins: the *facts* are correct, but the application of them is erroneous.

2. *Of the true nature of the phenomena displayed by anencephalous infants.*—It is justly remarked by Dr. Hall, that "the account of the phenomena presented by the anencaphalous infant, during the few hours of its extra-uterine life, drawn up by one well imbued with the distinction of the functions of the cerebral, or sentient and voluntary, and the true spinal excito-motory systems, would possess the deepest interest to the physiologist and pathologist.* But as this information still remains a desideratum, all that can be done, is to give those results which have been observed in the few instances of this nature that are on record. We learn that in these cases, independently of the functions connected with the circulation of the blood, secretion, &c. which are not connected with this investigation, sucking, deglutition, respiration, and the expulsion of the urine and feces were efficiently performed; that cries may be uttered; and that the motions of the limbs may be excited, either as happens in

* Lect. on Nerv. Sys. p. 53.

the first moments after birth, from the exposure to the air, or, subsequently, by the contact of any substance with the skin, as when any body is placed in the hand.

The very able view which Dr. Hall has taken of these cases, and the minuteness with which he has criticised their results, renders it unnecessary for me to enter into any detail on the present occasion. But as it is evident that these natural mutilations afford a most important field for observation; and as the interpretation of the phenomena displayed in them, must have great weight in determining the disputed question, as to the seat of sensation and volition, I shall consider, in succession, the several functions which were in operation in these cases.

Sucking.—The infants, in these cases, had the full power of sucking whenever the lips were touched, as by the little finger or by the nipple; and, therefore, it has been contended, that the contraction of the labial muscles was the result of the contact being so perceived by the medulla oblongata, as to excite sensation and volition. This deduction is erroneous, but it requires strong evidence to prove that in this case there was no consciousness, no volition; such evidence has not yet been furnished. It is, indeed, proved, that not only will the anencephalous infant suck, whether the lips be touched by the nipple or by any other body, but that the same thing occurs when the brain is experimentally removed: the following are most interesting illustrative experiments.

Expt. 8.—The brain was removed in a young puppy, which was then put to a large bitch, not the mother, but which was suckling at the time. The puppy on touching the mamma, threw up its nose and moved the mouth, trying to get hold of the nipple, which, however, was too large. My friend and colleague, Mr. Barron, to

whom I am much indebted for the performance of this and many other experiments, then moistened his finger with sugar and water, and put it into the mouth, when the puppy sucked, the tongue being wrapped around the finger. Mr. Barron also observed that the movements became more distinct when he pressed against the tongue.

Expt. 9.—The brain was carefully removed in another puppy; the animal performed the same actions as in the last experiment, only that they were more vigorous, which was attributed to the hemorrhage being less in this than in the former instance. But the most remarkable fact was, that as this puppy lay on its side sucking the finger, it pushed out its feet, in the same manner as young pigs exert theirs against the sow's dugs. In this and the former experiment the puppies laid still, or nearly so, when not touched; the slight motion noticed, and arising, as it is said, spontaneously, was doubtless caused by the irritation resulting from the severing those parts of the medulla oblongata which are prolonged into the brain.

In all such instances, however, it may truly be said that sensation is as easily excited by the contact of a finger as by that of the nipple; therefore, the main point remains still undecided. Fortunately there is a test, the truth of which can scarcely be questioned by those even who most strenuously advocate the theory, that sensation and volition are the source of these and the other actions of the anencephalous infant. Nature, in the generation of the marsupialia, displays, among the other extraordinary phenomena observed in those animals, several which are the exact counterpart of the actions of the anencephalous infant, and of the animal deprived of its brain.

In this interesting class of animals, the fœtus quits the uterus at a very early period: in the Virginian Opossum, uterine gestation continues twenty-six days; and in the

Kangaroo, according to the accurate observation of Mr. Owen, only thirty-nine days.* The fœtus of the latter animal, "resembled an earth worm in its color and semi-transparent integument; adhered firmly to the point of the nipple; breathed strongly but slowly; and moved its fore legs when disturbed;" its whole length from the nose to the end of the tail, when stretched out, did not exceed one inch two lines. The brain, in a mammary fœtus, one inch and a half in length, corresponds to the same organ in the human fœtus at the ninth week.† Are not these the very actions of an anencefalous infant, or of an animal without its brain? The mammary fœtus beathes, moves its limbs *when touched*, and by the contraction of its mouth grasps the nipple. It is true, it does not suck, because, at this early period, the muscular force is insufficient for such a continual action; and hence the beautiful provision of the compressor muscle, described in the interesting memoir of Mr. Morgan;‡ but it is certain that the lips, when they first are touched by the nipple, must contract upon and grasp it; and that, subsequently, the same action must incessantly be continued, till, as the development proceeds, the fœtus becomes, at times, separated from the nipple. Can it be imagined, that in this case there are sensation and volition in what can be proved, anatomically, to be a fœtus?

We learn, from Mr. Owen, that the brain of a mammary fœtus corresponds to that of the human embryo at the ninth week. Is it supposed, by any physiologist, that an embryo of that age, is endowed with sensation and volition? It is true, indeed, as Mr. Owen has observed, there is not an exact correspondence in the degree of the general development of the body, in the two cases, but,

* Phil. Trans. 1834, p. 343. † *l. c.*

‡ Trans. of Lin. Soc. Vol. XVI. p. 61.

as far as the brain is concerned, its exact stage of development is known.

But there is another fact which constitutes an important element in this argument. Mr. Owen has informed me, that the fœtus of the Kangaroo hangs continually on the nipple, night and day, for the period of three months. It is true that nature has made some beautiful provisions, by which the necessity for muscular action on the part of the fœtus, is greatly diminished; thus, although there is no terminal enlargement of the nipple when first the fœtus is attached, so that at that time the attachment *must* be the result of muscular action; yet, afterwards, the point swells out and is received into a depression on the tongue, provided for that purpose, it is, however, most probable, even under these circumstances, that the nice adjustment of the lips and tongue to retain the hold, and to prevent the milk escaping by the mouth, results from the contraction of the labial and lingual muscles. The second provision is the compressor muscle of the mammary gland, the use of which, in supplying the want of suction, has been so truly suggested by Mr. Morgan. It is probable that the action of this muscle itself, is an excited and not a voluntary action; a probability which would amount to a certainty, if, what under the circumstances can scarcely be doubted, the flow of the milk proceeds during the night as well as in the day; as, during the former state, the volition of the mother must either be so much impaired or entirely suspended, as to be unequal to stimulate the compressor muscle.

These remarkable facts establish, I conceive, the position that the action of the lips in sucking, and the movements of respiration can, and do take place in anencephalous fœtuses, in animals deprived, experimentally, of their brain, and in *all* new born animals, without the agency of consciousness, sensation and volition.

Deglutition.—The credit of showing that swallowing cannot be performed by the will alone; that the presence of a physical agent is necessary, is due to M. Magendie.* But then it is supposed that *sensation* is requisite to excite the proper muscles. It may be remarked, in limine, that this supposed necessity in itself involves an absurdity; because, if sensation were at all operative in the process, it could only be so by exciting the will; for, to say that an involuntary muscular action is the result of perception, is to deny the involuntary character altogether. This is only one of the remarkable contradictions in which the existing theory, as to the nature of the phenomena, evinced in the nervous and muscular systems, involves the science of physiology.

There are, however, distinct proofs that deglutition is *not* necessarily, although in the normal state it is incidentally, accompanied by sensation; for this process takes place when there is no sensation or volition, as during sleep, when the saliva is, from time to time, swallowed, and in coma, caused by compression of the brain. In the former state, it may, indeed, be questioned by some, whether sensation and volition are totally suspended. Dr. Hall, with that caution which he so strikingly evinces in asserting what is difficult of actual demonstration, in his table of the acts of the nervous system in relation to motion, leaves it doubtful whether sensation and volition are diminished wholly, or only suspended during sleep.† It appears that the true state of these faculties at that period is, that they are suspended; but that they are susceptible of being awakened by the application of any external stimulus, provided it be sufficiently intense. But it is certain that the contact caused by the passage of the

* Compen. of Phy. Translation of Dr. Milligan, 1823. p. 195.

† Mem. on the Nerv. Sys. p. 105.

saliva through the fauces, is not sufficiently energetic thus to awaken sensation, as, whilst asleep, we are entirely unconscious of the process.

Whatever may be objected to the preceding statement, it is not disputed, that in complete coma, however it may be induced, sensation and volition are altogether suspended. Now, in this condition of the percipient faculty, the power of swallowing *always* remains. It is true in in these cases, it is found that liquids poured into the mouth often run out again, and then it is said that the patient cannot swallow; but I am informed by my friend Mr. Tyrrel, that in *all* cases of coma, the act of swallowing is excited, provided the solid or liquid be placed in contact with the fauces.

The preceding remarks apply to that part of the process which relates to the fauces, in which we are conscious, though in a slight degree, of sensation. As regards the passage of the food through the œsophagus, there is no uncertainty; the food in that canal excites no sensation.

Here, then, is a state of coma in which it is certain that deglutition is not accompanied by sensation; and that an impression, not perceived by the individual, excites a most complicated series of muscular actions. This amounts to a demonstration that sensitive surfaces are capable of transmitting two impressions, essentially distinct from each other. Further, all this proves also, that numbers of muscles, supplied by the cerebro-spinal system, those of the tongue and fauces, are capable of being excited to contraction by two different classes of stimuli; the stimulus of the will, as in speaking or singing,—the stimulus of a physical agent, as in swallowing.

This part of the inquiry affords a close and striking application of the great principle which regulates the disposition of the nerves; namely, that the incident and reflex

fibres of associated parts, take their origin from similar portions of the spinal cord.* But to elucidate this principle, the several successive stages of deglution must be analyzed. The first act consists of placing the food upon the middle of the tongue, which is effected by an act of volition in the normal state; but which may be done by the hand of another person, as in coma, and in feeding the pigeon deprived of its brain; as soon as the food is thus placed, it is noticed that the lower jaw is raised, by which means the mouth is closed, and a fixed point afforded by the muscles which are afterwards to elevate the os hyoides, and with it the pharynx: next, the food passes rather farther back, and then the pharynx is raised: lastly, the morsel reaches the very base of the tongue and fauces, and then the bag of the pharynx, which has been previously raised, is expanded to receive the food. When this complex function is thus resolved into its various parts, the reason becomes apparent why the incident fibres forming a part of the gustatory nerve, which are distributed to the fore and middle part of the tongue, are derived from the same nerve, the fifth, which supplies the reflex fibres of the muscles that raise the lower jaw, and immediately afterwards the pharynx; it is that the antecedent impression made by the physical agent, the food, may excite the muscles necessary to effect the next subsequent action. And the same explanation may be offered, why the back part of the surface of the tongue is supplied, not by the fifth, but by the glosso-pharyngeus,† which also furnishes the nerve of that muscle, the stylo-

* See p. 48.

† Professor Müller has discovered that this nerve has two roots, and a ganglion on one of them; that, in fact, it is a compound spinal nerve. Mr. Mayo had previously shown that this nerve was connected with sensation and muscular action.

pharyngeus, by which the pharynx is opened, subsequently to the contact of the food with the fauces. The peculiar distribution of the n. glosso-pharyngeus and vagus in the pharynx and larynx, is perfectly explicable on the same principle; which affords a guide to a part of the wonderful intricacy of the nerves of the mouth, the fauces, and neck, which has been so long regarded by anatomists as a labyrinth to which it was almost hopeless to discover the clue. Sir C. Bell in his most interesting and important researches, clearly saw *one* cause of all these plexuses, when he pointed to the respiratory phenomena; but an equally important source of the peculiar distribution of these nerves, is the complex process of deglutition.

Respiration.—Notwithstanding the discoveries of Le Gallois, Bell, and others, the actions of the diaphragm and other muscles associated with this process, have remained until the true nature of the excito-motory phenomena was discovered, amongst the most obscure parts of physiology. My remarks on this subject will be limited principally to confirming those of Dr. Hall, who has so clearly shown the errors of all exciting theories, and has, also, so ably supported his own views.

According to Dr. Hall, the nervus vagus is the excitor of the actions of respiration, in consequence of transmitting the impression made by the carbonic acid on the surface of the air cells to the medulla oblongata, by the power of which the phrenic nerve is excited, and the diaphragm made to contract. He, also, correctly enumerates among the excitors, the trifacial and the spinal nerves, supplying the surface of the body generally.*

That the action of the diaphragm in inspiration, is, at

* See Memoirs, p. 77.

all times, the result of the impression of a physical agent on the surface of the lungs, is powerfully proved by several facts. If we abstain from breathing for a few seconds, the impression from the accumulation in excess of that which in a less quantity is the usual stimulus, carbonic acid, becomes so intense, that not only is great pain caused, but what is more to the purpose, the diaphragm is compelled to contract. The respiratory muscles are in the same manner excited to most violent actions, coughing, for example, by the application of any physical agent—by mucus, by irritating gases, by foreign bodies, either to the surface of the air cells, or to that of the windpipe, or larynx. The fact of the transmission of impressions, not usually or necessarily attended with sensation, is undoubted; but what is the medium of conduction? Dr. Hall asserts, and I think rightly, that it is the pneumogastric nerve, and he founds his opinion partly on the investigation of Brachet. As those experiments are so extremely important in determining this question, I thought it necessary that they should be repeated.

Exp. 10.—The vagus was divided on each side in a rabbit, which was then placed in a bell glass over water, according to the proceeding of Brachet.* The animal at first breathed in the same manner as if in the air, but much slower, because the section of the vagus causes the number of respirations to be diminished about one half. In a short time, he scratched the upper part of the glass; he was then quiet, but began to breathe with great labour, opening the mouth at each inspiration, and drawing in the air heavily; at the end of two hours he fell on his side and died, certainly "sans se débattre," *or being in any way violent or convulsed.*

Exp. 11.—A healthy rabbit of the same age as the last,

* Recher Exper. p. 134.

was put into the bell glass. Being more lively, he wanted at first to get out of his prison, but afterwards remained quiet till nearly the end of the experiment. He then scratched at the glass in a hurried, hasty manner; scratched his nose and mouth with his fore paws; licked the glass, and breathed very quickly, but he never opened the mouth to gasp for breath at each inspiration, as in the former case; after this excitement had continued five minutes he fell on his side *and died convulsed.* This rabbit lived a quarter of an hour longer than the former.

The results of these experiments are partly corroborative of those performed by M. Brachet; but it is certain that in the first there *was some uneasiness* produced; and yet, if the pneumo-gastric be the only conductor of impressions from the lungs to the brain, and to the spinal cord, causing in the former organ sensation, as when the breath is held, and in the latter, the action of the diaphragm, it is certain that *no pain* ought to have been excited in the first experiment. But, besides this difficulty, there are others which have not been explained. Dr. Hall conceives that after the division of the vagus, an animal breathes by means of its volition; and, as there is no doubt that the phrenic, like all the motor nerves of the spine has two roots, one spinal and one cerebral, there is certainly nothing to prevent the act of the will on the diaphragm. If, however, it is by the will that breathing is continued in these circumstances, it is certain that there must be some previous sensation excited, that the animal must experience some painful impression, the "besoin de respirer," which according to M. Brachet and Dr. Hall is destroyed by the division of the vagus.* These circum-

* The above statement is not at all opposed to the opinion advanced in another part of this Treatise, that sensation is not a necessary antecedent to volition.

stances induce me to conclude, that painful impressions *are* transmitted to the cerebrum after the section of the pneumo-gastric; and, it is probable, that this takes place through the medium of those branches of the great sympathetic, which are distributed to the lungs. It is well known, that although impressions made on parts of the body, such as the mucous surface of the intestine, which receive no other branches than those of the sympathetic, are not, under ordinary circumstances, carried to the brain; yet, if the impressions are sufficiently intense, they are so transmitted, and pain is the result, It is thus possible to conceive that volition may be excited, and that it is in this manner the action of the diaphragm is maintained after the section of the vagus. The only objection to this supposition is, that birds, and even dogs, and other animals, have been known to survive the division of these nerves several days; during which lengthened period, it is difficult to admit the possibility of voluntary action being continued, so incessantly, as occurs in respiration,* I mention all these circumstances, not because I doubt the correctness of Dr. Hall's theory; but to show that this is a subject requiring further investigation.

Action of the sphincter ani.—The mode of action of this muscle, appears to me to be one of the most difficult questions connected with the whole muscular system; for, whilst it is found that the sphincter loses its power, in compression of the brain and spinal cord, in man, as if its habitual contraction was produced by volition; it is

† M. Brachet attributes the actions of the respiratory muscles, which continue after the division of the pneumo-gastric nerve, to custom or habit; but this is an untenable position; it is certain that no muscle ever contracts without some definite cause of excitement.

found, on the contrary, in animals, that after the cord has been divided, and when it can be proved there is neither sensation or volition, the action of the muscle still continues. It has been supposed, by the advocates of the reflex action of the cord, that the contact of the feces is the cause of the sphincter contracting; and it is certain, as Dr. Hall has shown, that this muscle contracts, very forcibly, after the division of the cord, on a physical agent being applied, either to the margin of the anus, as by pricking the skin; or, when the mucous membrane is excited, as by injecting water into the rectum of the turtle, after the pelvis, with the spinal cord which it contains, has been detached from the rest of the body. An observation of Mr. Tyrrel tends, also, to show that the cord has a more direct influence over the sphincter than the brain; for he has observed, that, whilst in injuries of the head, causing coma, the paralysis of the sphincter does not immediately ensue; in injuries of the spine, producing complete paralysis of the parts below, the loss of power, in this muscle, is immediate. But, on the other hand, it may be remarked, that it is doubtful if feculent matter is always present in the rectum; and, even if this were the case, how can the loss of power be explained, in injuries of the brain, when the cord is healthy; and, as far as respiration, deglution, &c. are concerned, performs its office? In addition to which, it seems as if the action of the muscle is more of a voluntary than excited character; its contraction is not constantly required, because the feces are principally retained in the cells of the colon; and it is probable, that, as soon as they pass down into the rectum, they cause a desire to evacuate that canal, which is only prevented by a continual action of the will, producing a contraction of the anus. The exit of the

alimentary canal, it may be further supposed, is usually kept closed, merely by the elastic tissue entering into the formation of the sphincter and surrounding parts. This supposition is supported by the discharge of the feces, by all animals, and the human infant, as soon as they pass, in sufficient quantity, into the rectum; in the former instance, because there is no mental restraint; and in the latter, because volition is, as it appears, not yet in operation. This explanation, which has been suggested to me by Mr. Barron, is, certainly, well adapted to reconcile most of the phenomena connected with the action of the anus; but it is opposed by that experiment of Dr. Hall, which shows how powerfully the muscle resists, after the loss of volition.

The motions of the limbs, observed in these instances, and which form one of the most interesting branches of the inquiry, may be considered, most advantageously, at the latter part of this chapter.

3. *Of the evidence afforded by pathology.*—As I am anxious to avoid, as far as possible, a repetition of arguments which have been adduced by other writers, I shall very much limit these remarks; referring the reader to the Memoirs of Dr. Hall, where a most important body of evidence is recorded. The treatise of Mr. Solly may also be consulted with advantage.

The information derived from the present source is infinitely more satisfactory than any which can be obtained from animals; because, in vivisections, it is most difficult to know what is the result of the mischief done to other parts; and, especially, because there are no certain means of ascertaining what are the effects produced on the feelings of animals. Unfortunately, however, the

investigation of this branch of pathology is attended with peculiar difficulty; but, notwithstanding this, some definite results have been obtained.

It is certain, that, in every case of injury or disease, sufficiently severe entirely to destroy the power of the spinal cord to transmit impressions to and from the brain, there is, invariably, an entire and immediate loss of all sensation and volition, in the parts below the seat of mischief. The value of this evidence, when applied to the general question, as to the endowments of the cord, principally depends upon the possibility of proving, in opposition to the received opinions, that the cerebro-spinal system of the lower animals is, essentially, the exact analogue, in structure and function, of the corresponding parts in man. I shall, subsequently, endeavour to prove that such is the case. In this place, it will, therefore, be sufficient to state, that the effects produced by compression, laceration, or division of the human spinal cord, tend to prove, in a most forcible manner, that, in the lower animals, the same mischief is equally productive of a loss of all feeling and volition.

We not only learn, that in every case of severe injury or disease of the spine in man, there is an entire loss of sensation and volition in the lower limbs, but that motion may be excited in the parts thus paralysed. It is true, the evidence of the latter is very limited at present; doubtless, because sufficient notice has not been attracted to the importance of these phenomena. Dr. Hall relates a very interesting instance of paraplegia, in which, "when the integuments of the legs were pinched, and *more particularly when the sole of the foot* was tickled, the extremities were retracted with considerable force. A little cold water dashed upon the surface produced the same

effect, though there was no feeling of coldness. One leg was constantly in the flexed position, and, if straightened, immediately recovered it again. When the catheter was introduced, the penis was excited into a state of complete erection, an effect consequent upon the gliding of the instrument along the urethra; at the same time the legs were drawn up, and a twitching of their muscles was very obvious. The spinal marrow was found, post mortem, to be nearly severed in the neck." In another case of paraplegia, "the most extraordinary and forcible movements of the limbs took place whenever the bowels were relieved." In a case recently related by Sir B. C. Brodie, Bart., to the Royal Medical and Chirurgical Society, effects similar to those above-described took place on passing the catheter, the patient being totally unconscious of the contact of the instrument, and of its effect. Lastly, M. Brachet details a case, in which a person perfectly paraplegic became a father,—the *συνουσια* being "sans sensation," "sans secousse."*

An exactly analogous instance has been communicated to me by my colleague Mr. Barron:—"A girl, about fifteen years of age, who was a patient of Mr. Crosse at the Norfolk and Norwich Hospital a few years since, was affected with angular curvature of the spine, producing insensibility and paralysis of the lower extremities. On tickling *the soles of her feet*, which as an experiment was often done, the legs were immediately slightly retracted, although the patient said she felt nothing; it was further remarked, that on touching the *other parts of the feet* or *the legs* in the same manner, no effect was produced†."

The results noticed in these cases are full of interest.

* Memoirs, p. 64. † See Expt. 2.

They prove, first, *that in parts of the body indisputably deprived of all feeling and power of voluntary motion, contractions may be excited in the so called voluntary muscles, by impressions made on the skin;* secondly, *that this capability of exciting muscular contractions, is not equally possessed by all parts of the external surface of the body; but that the sole of the foot, which in walking comes in contact with the ground, is that precise part in which the action is excited in the most energetic manner.*

In reflecting on these cases, it is impossible not to be struck with their exact correspondence with those which have been recorded as being seen in rabbits, kittens, &c. after the section of the cord. Before I was acquainted with the cases of paraplegia above related, I had noticed, after the spinal cord had been divided in the rabbit, that there was a marked difference in the degree of excitability in the under part of the foot, covered with thick fur, and the thin skin of the leg; and that the most sensitive parts are not the most excitable. Dr. Hall had previously shown, that there was a similar difference in other parts of the body, thus,—"in a horse rendered insensible by a blow on the head, it was seen, that when lacerated or pricked by a sharp instrument, as a pin or a nail, on any part of the face or surface of the body, it was totally motionless; when, on the other hand, the eyelid was touched with a straw, the eyelid was forcibly closed."* In this instance it is evident, that the difference of excitability had reference to a preservative action,—that of closing the eye, to exclude a source of injurious irritation. But this explanation cannot be applied to the foot and leg; the difference in that case must be connected with some other

* Lect. p. 18.

provision of nature. What, then, is the inference here? It will, I think, hereafter be made apparent, that the susceptibility of the foot to the influence of physical agents, has reference to the function of the part,—in fact to loco-motion.

With respect to the effect produced upon sensation and volition, by injuries and diseases of the brain, the evidence is not so precise. It has however been established as a general conclusion, that in all instances in which an interruption takes place in consequence either of laceration or effusion, between the convolutions of the brain and any parts of the body, that those parts are immediately deprived of all sensibility and voluntary motion. This is daily witnessed in hemiplegia, produced by effusion of blood into the corpus striatum, causing a laceration of the ascending sensiferous and volition fibres derived from the crus cerebri. In these affections the excited actions of deglutition, respiration, &c. are but little or not at all impaired; and it is very probable it will be hereafter ascertained, that although the person has no power of effecting voluntary motion in the limbs, that combined movements may, for a limited time, be produced by tickling or otherwise exciting the skin. In reference to this subject, the fact above mentioned, that the susceptibility of different parts and organs to excitement by physical agents, is strictly applicable to the present question; for it is perfectly consistent with the known laws of the economy, that the reflex power should be much more energetic in reference to the vital functions of digestion and respiration, than to the animal function of loco-motion. Another circumstance may also here be stated, which will readily explain why, in cases of hemiplegia and paraplegia, no motion can be excited, after the lapse of a short time, by irritating the skin. A portion of the sciatic

nerve was removed in a dog, and also in two rabbits; it was found in the dog, that the power of exciting the muscles of the leg to contract, by pinching the sciatic nerve, was entirely lost at the expiration of eleven weeks; and in the rabbits the same result was observed at the end of five weeks.* Thus, it is perceived, that in a short time, if the muscles are entirely inactive, as they are in paralytic persons, in whom no attempt is made to excite them, they lose all power of being stimulated through the medium of the nerves.

Dr. Hall has properly attributed the spasms of tetanus, and various other affections, to the excitement of the reflex power of the cord. The following case, for the history of which I am indebted to my friend Mr. Bickersteth, is a most striking confirmation of the truth of these views. "Case of Tetanus, following a punctured wound of the foot, successfully treated by division of the posterior tibial nerve, by John Murray, M.D. E.I.C.S. Mr. W. P. æt. 15, a midshipman aboard the ship James Pattison, on her voyage to Madras in August 1832, trod on a rusty nail, which penetrated the left foot, between the metatarsal bones and the adjoining toes. The accident occurred whilst keeping his watch on deck, about 9 P. M., on the evening of the 15th; the patient continued his watch during the night, which was cold and stormy, and the wound gave him great pain. On the morning of the 16th, about 8 A. M., he complained of considerable stiffness about his jaws and throat, which was increasing rapidly; his countenance was most anxious, and his lips swollen and livid. As the jaws were nearly closed, a small piece of wood, a quarter of an inch thick, was with difficulty inserted between the teeth. At 10. 30, A. M.,

* Müller. Hand. der Phy. p. 615.

no beneficial effects were visible from the treatment;† the tetanic symptoms were increased; the spasms had partially extended to the muscles of the back, and the piece of wood was firmly indented by the teeth; the limb was cold, and he said "it was dead, except at the site of the wound, which was painful, and that he had little power of moving it." His pulse was at one hundred and twenty, and irritable, and his situation appeared to be one of extreme danger. I proposed the division of the posterior tibial nerve, by which the injured part was supplied, as the remedy holding out the greatest chance of success; this was agreed to by the surgeon of the ship (Mr. Leslie), and I accordingly performed it. Having found the nerve, which *was nearly twice its usual size*, I raised it on an aneurismal needle, and divided it by a rapid stroke of the scalpel. The division gave acute pain; and although he could not articulate distinctly before, on account of the closed state of the jaws, he *immediately opened his mouth with an exclamation;* and on looking at his countenance, I was asonished at the striking improvement in it. On being asked how he felt, he replied that "he was already much better, and that his leg had come to life again;" he expressed, at the same time, great inclination to go to stool. On the 18th, three days after the operation, all tetanic symptoms had disappeared; the numbness of the leg and foot, following the division of the nerve, had gone off; and he complained of pain extending from the knee downwards. From this date no unfavourable symptoms occurred. He finds no inconvenience in walking, or in the performance of any of his usual duties; he is in fact now perfectly well, with the exception only of want of sensation in the heel and little toe."

† The medical treatment has been omitted, having no immediate connexion with the subject under consideration.

This instructive case throws great light on the manner in which the terrible spasms are induced in traumatic tetanus. They are excited by the irritation of the incident fibres of the injured nerve, caused by some mechanical violence; and so long as this irritation is kept up, will the tetanic contractions persist. It may be objected to this explanation, that the division of the affected nerve has often failed in affording relief; but it must be remembered, when some time has elapsed, and the operation, for obvious reasons, is never performed speedily after the injury, that the inflammatory process has extended a considerable way along the trunk of the nerve; so that, when the division is practised near the original wound, the source of irritation and of excitation, is not removed. The spinal cord itself is even frequently affected in the progress of these cases. It is then evident that whenever the attempt of giving relief, by dividing the wounded nerve, is made, the operation should be performed early; and it is probable that if this were done whilst the inflammation was entirely confined to the nerve below the section, and that no other fibrils were implicated than those derived from the trunk which is cut through, success would always be the result.

Motions of the Limbs.—It has already been stated, that in the anencephalous infant, there was a considerable power of moving the limbs; but there is a most remarkable agreement in the accounts which have been given of these cases, that after the first exposure to the atmosphere, the child remained quiet, *excepting when it was touched.** Again, every physiologist who has divided the cord in living animals, and has then pricked or otherwise

* The motions of the fœtus, towards the middle period of gestation, are doubtless of the same character, and are caused by the pressure of the liquor amnii, set in motion by the movements of the mother on the incident nerves. For an account of these cases, see Hall, Lect. p. 48.

irritated the skin, has remarked the free motion which is thereby caused in the muscles which are called voluntary. Dr. Hall and Professor Müller, but especially the former, have collected a large body of evidence upon this subject, to show that these movements are not voluntary, nor accompanied with sensation: and whatever doubt may still exist on this point, with respect to the medulla oblongata, I conceive, that the researches of those physiologists, joined with the experiments related in this chapter, are sufficient to demonstrate that the spinal cord contained in the vertebral canal, cannot bestow feeling or the power of willing; and, therefore, it may be assumed, that when impressions are made on the skin of the foot of an animal, in which the cord has been divided, the motions which result are not voluntary. Although this property has been noticed by so many experimentalists; yet no one has offered any surmise as to its object. Dr. Hall, in his valuable works, limits the effect of the excito-motory system in the muscles generally, to the production of what is called their tone.* But he has further pointed out, that in a case of paralysis, motion was excited by tickling the sole of the foot; so that it is evident this acute observer has not overlooked the fact, that the influence of the reflex power is not restricted simply to giving tone to the muscular system. This subject is so important, that it requires a close investigation, in prosecuting which, it will be necessary to offer some remarks upon the true nature of the excito-motory phenomena in general.

It has been stated in a former note† that the motions excited by the application of a physical agent to the skin, after the division of the cord, are either of *a preservative character*, or *resembling the motions which the function of*

* Lect. on Nerv. Sys. p. 16. Memoirs, p. 38. † See p. 3

the organ requires. In these two points of view they may be advantageously considered.

With respect to the former position, it is acknowledged that all those operations of the economy which are necessary for the protection of the several organs, are wisely made to depend not on the will of the animal, but on a more certain agent, which is vaguely called instinct. The highly interesting inquiries of Dr. Hall, have shown that most of these instinctive motions are, in reality, excito-motory phenomena. I have endeavoured to establish this theory in a more decisive manner, by obviating the objections which arise from the experiments of Magendie, Desmoulins, and others. Whether the conclusions that I have drawn from the experiments recorded, as to the nature of the cries uttered by animals wanting the brain, and the attempt made to remove a source of irritation, will ultimately be recognized to be true or not; it is certain, that some preservative actions, for instance those of the iris on pinching the optic nerve, and those of the throat in deglutition, for the closure of the nostrils and larynx, are not necessarily attended with consciousness. In the same manner, it is to be presumed, that when any mechanical stimulus is applied to the skin after division of the cord, the limb is instantly retracted, not in consequence of any sensation which is produced, but because the incident nerves are irritated, and thereby excite the reflex power of the cord.

It is difficult, indeed, for the mind to conceive of a stimulant, which in the perfect state of the body causes the most intense pain, provoking such violent muscular actions as those related,* if no suffering be induced. But it is necessary to analyze what takes place, if by accident a part of the hand or leg touches any very hot body; the limb is instantly and involuntarily twitched away, and a

* See Expts. 4 & 5.

most painful sensation is excited. This latter, however, although in the normal state a constant, is not a necessary attendant. It may be thought, indeed, that such an explanation implies an useless infliction of suffering; but the accompanying pain is the best precaution that could have been devised, to prevent injurious effects, as it causes the animal to avoid in future all such sources of mischief. In those cases then, in which the limbs are retracted after the division of the cord from a source of irritation, we only behold the uncontrolled result of that beneficent provision, for removing the delicately organized structures of the body from injurious contact, which is also in operation in the perfect animal, although masked by the addition of sensation.

But it is further seen on thus irritating the rabbit's foot, that the motions excited are the same in character as those required for progression; or they are, as in the case of deglutition, those which the function of the organ requires. It will, I know, appear a very startling proposition that the application of a physical agent to the skin, in a part deprived of sensation and volition, can produce motions which have been heretofore regarded as purely of a voluntary character and it is proper at once to state that what is here advanced, is intended only to convey what are the *apparent* results of the experiments of Whytt, Blane, Mayo, Hall, Müller, and others, as well as of those performed by myself. Before, however, stating my own conclusions, it will be proper to show that the opinions of many eminent physiologists tend to support the idea, that the spinal cord has an equal, or even greater influence in the production of voluntary motion, as it is called, than the brain itself. Sir C. Bell,* who supposes that the brain is the organ of sensation, observes that the structure of the spinal cord

* See p. 10.

shows it to be something more than a mere nerve; that it resembles the brain in structure; and lastly that the brain does not operate directly on the frame of the body, but through the intervention of a system of nerves, the proper roots of which are in the spinal cord. This statement plainly indicates that the latter organ assists in motion by its own peculiar power; a suggestion which is proved to be correct by the capability it possesses of effecting combined motions of the limbs, after it has been divided.

Professor Müller, as it has been stated,* attributes a most important agency to the spinal cord, for he considers it to be the principal cause of the strength of what are regarded as voluntary motions.

The great majority of physiologists conceive, that in the lower classes of animals the spinal cord is immediately connected with the production of locomotion; but then they contend that this organ is the seat of sensation and volition: in fact it will hereafter appear that the only point in question is as to the real organs of feeling and of the will, for the spinal cord is allowed to be the seat of a motor power—is it volition, or the reflex power?

Dr. Bostock remarks that "the sensorium appears to be exclusively confined to the brain, but as we descend in the scale of beings to those whose functions, and especially whose nervous functions, are less perfect, it would appear that the sensorium is more extended. In some of the amphibia we may conjecture that the spinal cord partakes with the brain in all its faculties, and, as we advance to animals that have a still simpler organization, the brain entirely disappears, and the spinal cord seems to be substituted in its place. There is, however, reason to doubt whether, in this case, the animal possesses any degree of what can properly be called perception, and

* See p. 10.

whether the sole object of its nervous system may not be to convey impressions from one part to another, which are necessary for the functions of the animal, but which do not excite any ideas of consciousness."*

Mr. Mayo, in reference to this subject, has the following observations; "the preceding facts appear to establish an utter dissimilarity between the endowments of the nervous system, as it exists in vertebral, and in invertebral animals. That which can be divided, and either half retain its functions, is essentially unlike that, all the endowments of which depend upon the continuity of its different segments with one point."†

I have given these extracts, because they embody the prevailing ideas upon this most interesting subject; but, notwithstanding the great respect to which the opinions of these eminent physiologists are entitled, I feel myself called upon to state, that the above passages appear to me to abound in the most essential errors. It is, indeed, apparent that, in every systematic treatise, the most obscure statements prevail respecting the nature of sensation. Physiologists, although on these topics they always speak in a most vague manner, seem to imagine that there are, in fact, two kinds of sensation, one which is attended with perception and consciousness, and one which is not; but it implies an absurdity, to admit a sensation which is not perceived. In the case of vision, for example, the light falls upon the retina, and produces, by its contact, what is called an impression; but this impression is not converted into a sensation, until it has

* El Sys. of Phy. p. 152. It is proper to state, that the frequent references to this work are not made with any invidious intention; but because, among much other valuable matter, it contains a masterly epitome of all the leading doctrines of physiology.

† Out. of Phy. p. 212.

been perceived by the mind. These erroneous doctrines have mainly sprung from the notion, that muscular contraction is necessarily connected with sensation. But, when the true and full characters of the reflex power of the spinal cord come to be well and generally understood, which, at present, they are not, it will be apparent, that that which has been called by so many different names,* although it is most generally, perhaps, called *organic sensibility, is not sensibility of any kind;* but a capability, possessed by certain nerves (the incident), of receiving and transmitting the impressions of physical agents to the true spinal cord; which organ, by its peculiar power, excites muscular contraction, through the medium of the reflex nerves. The discovery of this, which I consider to be a principle of the highest importance in physiology, is due to Dr. Hall; for, although Professor Müller has made similar observations, yet they are more restricted, and are not so clearly distinguished from sensation. But, notwithstanding Dr. Hall has announced this as "a great principle of physiology," he has, hitherto, very much limited its operation in animal bodies, and has not alluded to its application to the other great class of organized beings, plants.†

It is evident, from the preceding quotations, that, according to the prevailing opinion, there is an essential difference in the character of the nervous system; not only in the vertebrate and invertebrate classes, when

* See Dr. Hall's Mem. p. 44.

† I have endeavoured to place the discoveries of Dr. Hall in that prominent place, to which they are so well entitled; and to assign to him the great merit which is due to his most valuable researches. It may be proper to state, that, in consequence of an absence from England, of several months, I only received the last work (the Memoirs) from my friend, Dr. Hall, after all the materials of this treatise were collected, and the first sheets printed.

contrasted with each other; but even among the several classes of the vertebrata themselves. That such ideas should have been received, in former times, is not, perhaps, surprising; but, after the definite results which have been obtained, by the profound and comprehensive researches of modern anatomists, it may well excite astonishment, that these vague doctrines still maintain their place in systematic works. The investigations of comparative anatomy, and the laborious inquiries into the process of development, have led to the establishment of one grand principle in the science of organization,—the unity of structure. There is no truth, in any branch of human knowledge, fixed on a more firm base than this,—that although nature displays immense fertility, in varying and modifying the form, and other physical characters of the several organs; yet, that there is, in no one instance, a departure from the first original type. This, the great law of the organic world, has been demonstrated in the osseous, nervous, glandular, and other systems, with amazing exactness; and, as a consequence, it has also been discovered that the human body, from the period of its first appearance, as a semi-fluid and shapeless mass, till it attains its perfect formation, passes through many stages, in which its several organs temporarily assume the permanent structures of the lower animals. There is, thus, a chain of evidence, in which no link is wanting, to prove what are and what are not analogous parts; and this test, when applied to the nervous system, is calculated to elucidate some of the most important of the excito-motory phenomena, and to point out the source of much of that obscurity, in which the principal questions of the physiology of the nervous system are at present involved.

By these means, we are able to demonstrate that the cerebro-spinal axis, of the lower animals, is, in all essential

particulars, the exact analogue of the brain and spinal cord, in man. From the results furnished by developmental anatomy, especially those derived from the philosophic researches of Professor Tiedemann, we learn that the brain of man, in the successive stages of its formation, bears not only a general resemblance to that of the inferior classes of the vertebrata; but that there is a perfect identity of parts, in the encephalon of the human embryo, and the permanent organs which constitute the perfect brain of fishes, reptiles, birds, and mammalia. So close, indeed, is the resemblance, that it would be difficult to distinguish between the brain of a fish or reptile, and that of an embryo, in a corresponding degree of formation. It is true that, in the human brain, there is, subsequently, an enormous development of those parts of the organ, to which all concurrent testimony points, as being the seat of the intellectual faculties; but, although the hemispheres are thus augmented, the original and essential parts still exist; and, doubtless, have as close an analogy, in function, with the corresponding parts of the brain of the lower animals, as they had in the first moment of their formation. So accurate, indeed, is the knowledge on this subject, that the anatomist, by examining the brain of one of the lower classes of the mammalia, or other vertebral animal, can precisely determine to what exact period of the development of the human cerebrum it corresponds.

Notwithstanding the complete establishment of this, certainly the most important principle of the science of organization; it is still maintained that properties, that is to say, sensation and volition, which are known to be the special attributes of certain parts of the human brain; and which parts, although developed in an inferior degree, have still a real existence in the lower animals, become translated, in these instances, to another independent organ, posses-

sing its own peculiar endowments, the spinal cord. If such a mode of inducing facts be recognised in physiology; if, in fact, the function of one organ may thus be transferred to another and distinct structure, merely to reconcile the anomalies of a crude and ill-supported hypothesis, all the great truths of modern anatomy have been discovered in vain; for, with equal consistency might it be asserted, that the liver, which varies much more in its physical characters, in the several classes of animals, than the brain and spinal cord, performs, in the crustacea, some additional functions (such as secreting urine) which it does not accomplish in man. But, if any fixed principles are ever to be established, in the investigation of the phenomena displayed in the animal economy; it is necessary to admit, that, where there is such wonderful uniformity of structure, there must be uniformity of function; as it is certain, however difficult it may be to reconcile such a truth with the acknowledged doctrines of the day, that the laws of nature are simple in their character, and definite in their operation.

When it is surmised, by some physiologists, that the faculties of the brain are in two great classes of the vertebrata, reptiles and fishes, transferred to the spinal cord; it cannot be a matter of surprise, if another writer asserts, that, in the invertebrata, the nervous system is essentially unlike that of the vertebral tribes. Such a doctrine, when thus generally applied, is, indeed, equally opposed with the preceding, to comprehensive views of animal organization; and the only reason why the inconsistency is not so glaring, is owing to our ignorance of the true character of the structure of these lower animals. After what has been observed, in the former part of this treatise,* it is

* See p. 43.

only necessary to state, that, in the immense division of articulata, there is, unquestionably, a cerebro-spinal system, corresponding with that of the vertebrata; and that, although the great varieties of form displayed in those numerous and diversified animals, which are at present classed together, under the term of mollusca, necessarily involve most important changes in the disposition of the central masses of the nervous system; yet there can be no doubt that the ganglions placed in the head, or around the œsophagus, constitute the true seat of sensation and volition; and perhaps, also, in part, or entirely, of that reflex power which, in animals with a more symmetrical form, is the property of a separate nervous centre, the spinal cord. This is a division of the animal kingdom, however, in which the most important discoveries, relative to the true nature of their nervous system, may be anticipated.

These details were required, to prove that the motions of the limbs, which take place when the connexion with the brain is destroyed, are not the result of any kind of sensation or volition; and it may now be advisable, briefly to direct the attention of the reader to the immense importance of physical agents, in the production of some of the principal phenomena of life.

There was a period, and that not remote, when all the functions of the animal body were supposed to be dependent on what was called the vital principle; and yet, so complete has been the revolution in physiological doctrines, that, at the present time, it is acknowledged that most of the organic functions are much more dependent on the influence of physical, than of vital agency. In fact, in surveying the varied operations which are proceeding in the animal body, little else is discovered than the incessant and reciprocal action and reaction of physical agents, and of that vital power which is possessed by the nervous

system. A glance at a few of the most essential of these operations, will show the justness of this observation.

The discovery, by Dr. Prout, that muriatic acid is present in the stomach during digestion, joined to other facts observed in that process, prove that chemical action is intimately connected with the formation of chyme. Dr. Bostock, indeed, doubts if this acid is the efficient cause of digestion; principally, as it would appear, because, as there is no evidence of the existence of the muriatic acid in the stomach, previous to the introduction of food, he infers that it may, in some way or other, be developed during the process of chymification.

But this uncertainty is obviated by the very exact and important observations of Dr. Beaumont, who has shown, that the gastric juice only flows into the stomach when the internal surface of that organ is excited by the contact of food or any other mechanical irritation; and that this secretion does not become changed in its chemical properties during digestion, but that at all times it contains muriatic acid.

The valuable researches of Dr. Edwards, which afford such ample materials for the solution of some of the most intricate questions in physiology, tend powerfully to support the opinion so long entertained, that the generation of animal heat is the result of those chemical actions which take place in the lungs during the process of respiration.*

* This hypothesis is not opposed to the facts which show that the nervous influence is connected with this process; thus, for instance, the division of the vagus nerve causes a decrease of temperature, but this is, probably, only an indirect effect of abstracting from the lungs so large a source of nervous power. This section produces three effects, each of which, by obstructing the combination of oxygen and carbon, must necessarily lessen the quantity of heat generated; first, the number of respirations is greatly diminished—in a rabbit about one half; secondly, the quantity of blood passing through the lungs is decreased, owing to the great embarrassment of the pulmonary circu-

In the process of secretion again, where so much has been attributed to the nervous influence, the discovery of modern chemists, by showing that, perhaps, with the exception of gelatine and the spermatic animalcules, every substance met with in the glandular fluids, exists in the blood; and the highly important investigations of Dutrochet, Magendie, and others, relative to endosmose and exosmose, distinctly prove that the action of the glands is principally limited to providing a fit machine, not for the formation, but for the separation from the blood, of those varied fluids which are met with in the animal body. This view of the process of secretion is greatly strengthened by the vast body of evidence for which the science of anatomy is so deeply indebted to Professor Müller. In his valuable treatise on the glands, this profound anatomist has shown, that the great distinction among the several classes of these organs, does not consist in any essential variety of organization, for the type is uniform, but in an infinite diversity of the mechanical characters of the secreting canals.

From the comprehensive inquiries of modern physiologists then, it is evident, that what are called the vital functions, are in reality, principally the result of physical operations; and it is thus not difficult to perceive that the received opinions of physiologists on these subjects, must

lation, indicated by congestion and effusion; thirdly, the air passages become loaded with mucous fluids, so as to obstruct the free contact of the atmospheric air with the venous blood. It may further be remarked, that, with respect to the effects of artificial respiration, kept up after decapitation, if the exact balance which, in the normal state, is maintained between the quantity of air received into the lungs in inspiration and that emitted in expiration, be not preserved, a decrease of temperature must ensue, in consequence of the proportion between the quantity of air and blood contained in the lungs being disturbed.

undergo even a much more important modification than they have hitherto experienced.

The discovery of the reflex power has carried the influence of physical agents into the domain of the animal functions, in which, there is little doubt, it performs a part equally extensive and varied as in the phenomena of the organic life. Reiterated instances prove, that what are considered as voluntary muscles, are excited to the most complex motions, entirely independent of volition, by the impressions of physical agents on the associated surfaces of the skin and mucous membranes. It has been long known, indeed, that particular muscles are susceptible of contracting independently of the will; and, *in every case, in obedience to the application of a physical agent;* but then, it is thought that these muscles are restricted to the parts connected with the organic functions. This opinion is not, however, true; for a great number of the muscles of the extremities are called into involuntary action in sneezing, coughing, and vomiting.

An eminent physiologist, indeed, has distinctly stated that *all* muscular actions, are, in the first instance involuntary; that some continue so during life; but that there are some over which we gradually acquire a voluntary power, and among these, deglutition is enumerated.* The two first statements are correct; but with respect to the third position, although it is true that the mind, as it becomes developed, does acquire a control over the muscles, which are called voluntary, it is only in the performance of actions which are *strictly* voluntary in their character; the excited actions of those muscles remain throughout life as involuntary as in the first moment of existence. The act of deglutition, for example, is as invo-

* Bostock. El. Sys. of Phy. p. 776.

luntary, or excited that is to say, in the adult as in the new born child, or in the animal deprived of its brain, the only difference consisting of the manner in which the food is previously collected on the tongue. Dr. Hall in the following passage, has offered the real explanation of all these apparently conflicting phenomena. "The truth is," he observes, "that the intellectual functions are daily developed during the first years of life, and *obscure* those of the excito-motory; but the latter are not *enfeebled* during this change, which is one of *superaddition* not of *substitution.*"

Since, then, we find that in the beginning of life *all* the muscles execute involuntary or excited actions—that although the will subsequently acquires a control over certain of the muscles, which still retain their capability of being excited; why is it to be supposed that those of the limbs, which are proved by every kind of evidence, by experiment, by the anencephalous infant, and by pathology, to possess a most remarkable power of being so excited, as to produce combined motion when all sensation and volition are destroyed, do not retain the same susceptibility in the perfect animal? The fact is that exactly the same thing happens here as in deglutition—the operation of the physical agent, and the excited motions which result, are obscured by the presence of the proper cerebral faculties. Is it more wonderful that the muscles of the leg should be stimulated to contraction by the contact of the whole surface of the foot with the ground, than that a few grains of snuff should, by their impression on the schneiderian membrane, call up the action of the so called voluntary muscles of the shoulders and arms?

As far as insects are concerned, it is certain that not only are free motions of the wings excited after decapitation, but that some, the mole cricket for example, are able to

walk for a considerable distance. Now, under these circumstances, the spinal cord must either stimulate the muscles by volition, which it has been shown does not exist, or by its proper reflex power, excited to action by the impression of a physical agent on the limbs. In frogs, it may also be observed under favourable circumstances, and when the cord is divided high up towards the neck, that on pinching one of the toes or other part of the foot, both legs are not only drawn up towards the body, but are often forcibly struck out, as in swimming or leaping. In rabbits, kittens, and puppies, the motions caused by irritating the skin, are not vague and indefinite, but consist of regular and successive movements, similar to those performed in locomotion. The pigeon, likewise, which from losing its brain, had been deprived of its sensation and volition, still retained the power of flying when thrown in the air.

These are striking facts, and indicate the existence of a power, by the operation of which the motions of progression may be excited when volition is destroyed. So deeply impressed is the mind, however, with the idea of our motions in walking being altogether voluntary, that it is almost impossible to conceive how the mere circumstance of the foot coming in contact with the ground, can cause the muscles of the lower extremities to produce all the complicated actions which are necessary to take another step; and yet it is certain that these motions are regularly effected, when the mind is entirely abstracted from all thoughts of the actions that are required; so that at these times, which are so extremely frequent, the movements of progression become automatic. It is often said, indeed, that under such circumstances, the muscles contract from habit; but such a vague explanation becomes quite insufficient when it is recollected how

invariably every natural phenomenon is preceded by a definite cause.

It may be thought that the theory here advanced involves in itself a contradiction; because, if it be admitted, it might be supposed that whenever the foot of an animal comes in contact with the ground, the muscles of the leg must of necessity contract. It is certain, however, that volition not only possesses the power of exciting what are called the voluntary muscles, but that it can also so control them, as to stop the effect of the impressions transmitted by the incident nerves. This is constantly evinced in experiments, in which, when the spinal cord is divided, and the foot is irritated, the most violent motions are produced, and often several times repeated, without the animal having any control over the hind limbs; whilst, if the fore leg, which retains its connexion with the brain, be similarly excited, little or even no effect is produced; evidently because the excito-motory actions are checked or prevented. In the human body, facts of a similar nature may be daily observed; thus, with respect to the diaphragm, we can, to a limited extent, control its action, although it is certain that the stimulus of the carbonic acid to the lungs is in operation.

If the excito-motory phenomena be carefully investigated, it becomes evident that this controlling influence of the will is regulated, according to the wants of the economy, in obedience to certain laws. Thus, those motions which are of a preservative character, such as the closure of the eyelids, on the cornea or cilia being touched, or the protection of the larynx during deglutition, are altogether removed from the influence of volition; whilst, on the contrary, the muscles which are necessary to locomotion, are, in the normal state of the system, in every animal possessing a brain, placed under

the full and perfect control of the will. But, if the incident nerves are stimulated in excess, as in burns or tetanus, then no check which the individual can exert is able to prevent the most violent muscular contraction. Between these two extremes there are many shades; in every instance, however, the power of the will is always determined by the importance of the function with which the motions are connected, and the intensity of the stimulus.

Lastly, it may be remarked, that, if such a modification of volition really exists, it is certain there must be conductors for this special purpose, distinct from all the other parts of the apparatus of sensation and volition. Without pretending to designate any particular structure, as being the organ of transmission, it may yet be stated that it is, doubtless, confined to the cerebro-spinal axis; in the component parts of which—the brain and spinal cord—there are various fibrous structures, such as the anterior column of the latter, the uses of which still remain to be discovered.

CHAPTER V.

GENERAL RESULTS.

My great object, in this inquiry, has been to determine the properties of the spinal cord and medulla oblongata. Until the true seat of sensation and volition be satisfactorily ascertained, it is certain that the whole physiology of the nervous system will remain involved in that state of confusion, which, at present, is so conspicuous in every systematic treatise. In perusing these works, the reader constantly meets with vague speculations, and contradictory accounts; and that too, in relation to subjects of the highest import, not only to the science of life, but likewise to that of pathology. In offering these observations, I am actuated by no reproachful spirit; for, in common with every individual, whose pursuits lead him to the frequent and repeated investigation of the phenomena displayed in organized bodies, I have been incessantly foiled in the attempt to convey to others some satisfactory and consistent account of the complex operations of the animal economy. In fact, until the principle of the reflex action of the spinal cord was discovered, it was impossible to reconcile, not merely the conflicting results of physiological experiments, but the apparent contradictions presented by so many of the processes, which are the most essential

to the maintenance of life. The consequence of this total ignorance of the general laws of the nervous system has been, that the physiologist, instead of any definite principles, has been obliged to remain satisfied with vague, and often absurd surmises, respecting the nature of sensibility, instinct, and contractility. Hence the multitude of theories and hypotheses respecting animal and organic sensibility, irritability, excitability, vis nervosa, and so forth; hence, also, that incessant dispute, concerning the respective properties of the nervous and muscular systems. No one who is not engaged in the actual practice of teaching, can duly estimate the immense importance of the excito-motory principle, in obviating, reconciling, and explaining, that mass of contradictions, which, like a cloud, has obscured all the great questions of physiology. This truth, from the nature of my pursuits, having been forced upon me, I was induced to investigate this principle in all its bearings; and I was not slow to perceive that it afforded, as it seemed to me, a clue, by which all the phenomena of sensibility and contractility might ultimately be revealed.

In the present treatise, it is not in any way pretended that such comprehensive results have been established; the prosecution of so great an undertaking will, doubtless, require the combined labours of much more talented individuals. I have only endeavoured to clear away the principal of those obstacles which lie in the very threshold of the inquiry; and to point to what appear to be the legitimate inductions of the facts we now possess.

Without entering into any of the long-disputed questions, concerning the properties of the nervous and muscular tissues, such an inquiry being entirely foreign to the object of this investigation, it will yet be necessary to

state, that the following axioms appear to be susceptible of satisfactory proof.

1. That the source of all power, in the nervous system, is the grey matter.

2. That the white fibres are merely conductors.

3. That there exist, in the nervous system, two great divisions*,—A, the true cerebral; consisting of the hemispheres of the cerebrum, and the lobes of the cerebellum; of the true sensiferous, and the true volition fibres of the cranio-spinal nerves:—B, the true spinal; comprising the grey matter of the spinal cord, and the incident and reflex fibres of the cranio-spinal nerves.

4. That there is no special order of respiratory nerves.

5. That there is but one kind of sensibility possessed by animals; that, namely, which is perceived by the mind.

6. That this sensibility is, in the higher animals, the invariable and inseparable property of the cerebral hemispheres, inclusive of the lobes of the cerebellum; and, in the lower animals, of that part of the nervous system which can be shown to be, in office, the true analogue of the brain.

7. That volition is the inseparable attribute of the cerebral hemispheres, and lobes of the cerebellum.

8. That the spinal cord, in every class of the animal kingdom in which it exists; and the analogous part, in those animals in which, in consequence of variety of shape or other circumstances, this cord cannot be detected in the usual form, is the inherent seat of a property, totally distinct from sensation and volition, called the reflex power.

9. That the reflex power is never exercised, without the

* The question relating to the great sympathetic is briefly considered at the end of this chapter.

excitement caused by the application of a physical agent to the external and internal surfaces of the body.

10. That contractility is the special property of the muscular fibre.

11. That contractility has no necessary connexion with sensibility.

12. That contractility cannot be exercised without the application of a stimulus.

13. That this stimulus consists of — A, volition; B, the reflex power of the spinal cord; and, *perhaps,* C, of a direct application of a physical agent to the muscular fibre itself.

1 and 2. It has been stated in the third chapter, that the mode of connexion between the two compound substances of the nervous system, the grey and the fibrous, is apparently uniform; that is to say, that it consists of an incrustation of the fibres by the grey matter, so that alternate plates, as it were, are formed, and which are very distinct in the gasserian ganglion and convolutions of the brain when hardened in alcohol.* Those who have seen the incessant and numerous currents in a part apparently so little vascular as a frog's foot, will be able to form some estimate of what must be going on in the grey matter of the nervous system, a part so abundantly supplied with blood, that anatomists formerly believed it to be composed entirely of vessels. It is, then, through this precise part, where the two substances come together, in the form already described, that innumerable torrents of blood are incessantly rushing; and it is proved, that, if this current be totally interrupted, even for a few seconds, the power of the nervous system is suspended, and, in less

* Mr. Mayo has represented in the convolutions the appearance resulting from the connexion above described.—*See Engravings on the Brain.*

than a minute is annihilated.* The true idea then, of the grey substance is, that it consists of white fibres, separated from each other by portions of the grey matter, and of incessant currents of blood rushing through the intervals. These considerations, joined to the facts which have been already adduced, leave no doubt as to the exact seat of the nervous power.†

3. The proof of this proposition rests, as far as the ana-

* See p. 19.

† Mr. Faraday, in the lecture which he delivered at the Royal Institution, on the excito-motory theory, stated, that "the agent of the animal portion of the nervous system might be electricity." (British Annals of Medicine, No. 8, p. 227.) This is the repetition of an opinion entertained by many eminent physiologists; but it assumes a new degree of importance, when it is announced by one of the most profound chemists in Europe; and, especially when it is considered in connexion with the important fact which I have ascertained, that the material instrument in which the reflex power of the spinal cord is generated, is precisely of the same character with that by which all authorities are agreed, the mind effects its operations. If then, it should ever be demonstrated, that the excito-motory phenomena are the result of an electrical action excited in the grey matter of the cord, it must follow that those intellectual faculties, sensation and volition, which all animals provided with a true brain possess, operate by the agency of electricity. In advancing such an opinion, I feel it incumbent to point out, that although the instrument may be the same, the mode in which it is called into action is totally dissimilar in the two cases; for, whilst in each it is evident there must be a *first cause*, it is known in the instance of the spinal cord, that the reflex power is excited by the application of a physical agent to the extremity of the incident nerves; but in that of the brain, the excitor is an immaterial agent, the mind. Even then, if it be hereafter proved that a galvanic apparatus does exist in the brain, we have still made no approach to the nature of that cause which sets it in action; for, without entering into the metaphysical question, whether or not all our ideas result in the first instance from the impressions of sensible objects, it is certain that after the mind has once acquired, by whatever means, the materials of thought, it can originate a train of reasoning altogether unconnected with external circumstances; so that all these physiological inquiries, refer only to the instrument which it has pleased the Creator to provide for the operations of the intellectual principle. Such an opinion, thus plainly stated, will probably call forth the rebuke of those narrow minded persons, who perceive in the gigantic progress which is being

tomy is concerned, on the same basis as the discovery by Sir C. Bell of the two functions of the spinal nerve; for, as the two roots in the compound nerve were supposed to indicate the existence of two separate faculties, so the demonstration of four roots points to the inference that there are four different functions. The physiological evidence, although not so exact, is sufficient to establish the deduction, that the grey matter of the cord, together with the fibres of the anterior and posterior roots attached to it, constitute an apparatus which is independent of the brain, and which may even exist in all its integrity, as in the anencephalous infant, without the latter organ; and that it is these structures which form the true spinal or excito-motory division of the nervous system. It is difficult in the investigation of any undecided point of anatomy, to conceive of any more satisfactory proof of the existence of a special endowment, in a particular part of the nervous system, than that which is afforded by the fact, that the precise structure which is alledged to be the seat of the property enlarges in exact proportion with the activity of the property itself. Now this proof is afforded in its fullest extent in reference to the question under consideration, by the facts which have been discovered in developmental and comparative anatomy. The results obtained from these sources demonstrate, that exactly in the same ratio as the excito-motory actions predominate in the young of the human species and higher animals, and in the adult of the inferior families, over the true cerebral phenomena, is that particular part, the grey

made in every department of human knowledge towards the discovery of first principles, only so many steps in the march of infidelity. Those who are inclined thus to reason within the circle of their own prejudices, will do well to consider the enlightened and ennobling view taken of the true objects of science, by one of the master spirits of the age. (Herschell's Discourse on the Study of Natural Philosophy, p. 7.)

matter of the spinal cord, which I contend is the seat of the reflex power developed, when contrasted with that fibrous structure which forms part of the true cerebral system. This is the true explanation of the preponderance of the grey matter noticed in the spinal cord of young vertebral animals, and in the ganglions of the nodulated cords of the invertebrata. A further corroboration of the views here advanced, is furnished by the observation of Desmoulins, that it is the external part of the cord which transmits sensation and volition; the destruction of the central portion has but little influence on those functions.

By a reference to the plan, *(See fig. 3.)* it will be seen that when the spinal cord is divided in a living animal, the only part injured, beyond the severe mischief which necessarily is inflicted in making the section itself, consists of the ascending fibres comprising the pure sensiferous and the pure volition fibres, which form a part of the cerebral apparatus; the true spinal apparatus remains intact. It is not, however, to be expected, after such an operation, that the excito-motory phenomena will be displayed with their pristine force: the mechanical violence and the loss of blood from the arteries of the cord are quite sufficient to explain the great diminution which was noticed in the reflex power.

It is necessary to state, that I consider the reflex power to be strictly limited to the spinal cord in its cranial and vertebral portions; and in no way to be connected with the true cerebrum.

In connexion with this subject, I may refer to a point of considerable interest relative to the respective functions of the anterior and posterior roots of the spinal nerves. In the course of the experiments related in the previous chapter, it was often observed that on touching the *pos-*

terior column of the spinal cord, that motion was produced. This fact, which has also been remarked by several experimentalists, constitutes the principal groundwork of the objections urged against the doctrine of Bell. Although I am, myself, perfectly convinced of the exactness of the deductions drawn by this distinguished physiologist from his observations and experiments, and although they have been generally received by the first authorities in Europe; yet, whilst such men as Meckel, Rudolphi, and Weber, still regard these doctrines as being conjectural, the question as to the functions of the anterior and posterior roots of the spinal nerves cannot be considered as determined.

On irritating the posterior part of the spinal cord, it is, as I have stated, often observed that motion is excited.* In connexion with this subject, Mr. Barron, with great justness remarked, that inasmuch as irritation of the incident nerves, where they terminate in the skin, excites muscular action, it must necessarily happen that when these nerves are irritated where they enter the spinal cord, a similar result will be produced. It is certain when the posterior surface of the cord is irritated, that sometimes the incident nerves will be touched, and whenever this occurs muscular action must take place. In this manner it is easy to reconcile those conflicting results, which have hitherto constituted an unexplained anomaly in the theory of Bell and Magendie.

4. Dr. Hall, has, I conceive, given the real explanation of those nerves which are associated in the actions of respiration. He says, "I perfectly agree with Sir Charles

* Dr. Elliotson, in alluding to this circumstance, attributes it to a peculiar relation between the nerves of sensation and those of motion, that originate at the same portions of the nervous system. The real explanation is that stated in the text.. (El. of Phy. 4th edit. p. 217.)

Bell in the opinion that the respiratory is entirely distinct from the other subdivisions of the nervous system; but I venture to differ from him in viewing the respiratory as but *a part* of a more extensive system—as an *excited* and not a *spontaneous* function—as *originating*, when the cerebrum is removed, in the pneumo-gastric *as its excitor*, and not in the medulla oblongata." But, notwithstanding this modification of the beautiful theory of Sir Charles Bell, that great physiologist made an important advance towards unravelling the mysteries of this intricate process, when he forcibly called attention to the fact of so many nerves being associated together, producing the complicated movements of the face, throat, and chest, which are displayed in breathing. Neither did the circumstance, that in particular and extraordinary states, the phenomena of respiration call up the action of almost every muscle of the body, escape the notice of this acute observer; it was this consideration which induced him to suppose that *all* the spinal nerves, as well as those called more especially respiratory, received from the imaginary *tractus respiratorius* fibres distinct from those of sensation and volition. This idea of the necessity of an additional set of nerves, was a close approach to the more comprehensive and correct views of Dr. Hall; and after the account which I have given of the anatomical relations of the spinal nerves, it is easy to perceive the true state of the question; Sir Charles Bell imagined that there was a distinct class of fibres, which he conceived ministered only to the acts of respiration; whilst I have shown what Dr. Hall has announced, that all the common nerves of sensation and volition contain a peculiar class of filaments, which are subservient to the production of all the excited actions of the body, including, as an important part, those of respiration.

With the knowledge we now possess, it is easy to perceive the cause of all these conflicting opinions respecting the properties of the cranial part of the spinal cord. The medulla oblongata only differs, I believe, from the vertebral portion of the cord, in consequence of having attached to it that nerve, the pneumo-gastric, which Dr. Hall so justly calls the excitor of respiration. It is this which elevates the oblong medulla so high in the scale of the nervous centres; it is this which constitutes it the essential agent of animal life.*

5. If it had not happened that physiological writers, in consequence of the difficulties which are involved in all the existing theories, had admitted two kinds of sensibility, animal and organic, one of which, it was supposed, was, and the other was not perceived by the mind, it would have been surprising that such a distinction should ever have been attempted. If we free ourselves for an instant of all these confused notions, it becomes evident that there is but one kind of sensibility,—for the very term sensation implies something of which the mind is conscious; thus, for example, if I touch a piece of wood with the finger, a certain effect is produced on the ends of the sentient nerves, which is called an impression; and this impression, when it has been transmitted to the brain, is by the agency of that organ perceived, and then, but not till then, sensation is produced.† The blood makes an impression on the internal surface of the heart, but as this impression is not under ordinary circumstances transmitted to the brain, it is not perceived, and, consequently, sensation is not pro-

* For classification of the nerves, see Appendix.

† Dr. Bostock, in common with other physiologists, not only admits that sensation may exist without perception, but he increases the difficulty by using the terms *impression* and *sensation* synonymously in those parts of the body, the skin for example, in which true sensation unquestionably exists. (El. Sys. p. 143.)

duced. By this illustration, it is not meant to be denied that the heart, the stomach, the intestines, &c., are endowed with a capability of receiving the impressions of the blood, the food, or any other physical agent; or that these impressions do not excite the muscular action of these organs. All I mean to express is, that these impressions made on the heart, stomach, and so forth, do not cause sensation—they excite motion but not feeling. If the term sensibility be employed to indicate simply the power which the nervous system, viewed in a collective manner, has of receiving every kind of impression, whether attended with perception or not, there is only an inexactness of phraseology, and not a positive error; but inasmuch as the opinions of many persons are influenced more by the words than by the facts they are intended to convey, it is indispensable to banish from physiology, a laxity of expression which has been productive of incalculable confusion. The terms sensibility and sensation which are generally used synonymously, although in fact the former is the cause, and the latter only the effect, ought in future to be restricted to sensation attended with consciousness, which, indeed, with the exception of physiological writers, is the meaning universally attached to the expression. As to that power which the true spinal cord possesses of receiving impressions which are not attended by consciousness, but which produce motion, it has no necessary connexion with sensation, and, therefore, should be distinguished by a separate name; and although the word is not free from objection, yet, as it corresponds with the name given to the phenomena which result from the property in question (the *excito-motory)*. The latter may be termed *excitability*. The source of all this fallacy has been clearly pointed out by Dr. Hall.*

* Mem. p. 43, et seq.

6, 7. In the preceding chapter I have entered so very fully into these questions, that it is only requisite to state in this place, that the prevailing opinions according to which sensation and volition are either the properties of the spinal cord in general, or the medulla oblongata in particular, have arisen partly from unphilosophical views of the cerebro-spinal system in the vertebral and invertebral classes of animals, and partly from the false interpretation of the actions displayed in the anencephalous infant, and in animals experimentally deprived of their brain. It must be confessed that some of these phenomena which have, hitherto, never been accounted for, such for instance as the cries uttered, and the attempts to remove a source of irritation, are, as it would appear, such palpable indications of the persistence of feeling, that it is necessary entirely to change our ideas on this subject before the mind can arrive at any other conclusion. I have, however, experimentally proved that the limbs perform defensive motions when there is no sensation, and have further endeavoured to prove, by a consideration of the cries of new born animals, that such sounds do not indicate the existence of any feeling. From what has been observed of the vagitus of new born infants, it may be expected that young animals when deprived of their brain, will utter cries and yet suffer no pain.

8. If the proposition before advanced be granted, that the grey matter is the source of power, it must follow that the spinal cord in common with the other great nervous centre the brain, constitutes an independent seat of nervous energy. The interesting researches of Desmoulins strongly support this opinion, by showing how regularly the cord increases in size, cæteris paribus, according to the energy and extent of the muscular action. It is, indeed, supposed by this writer that the delicacy of the

sense of touch, depends on the relative magnitude of the cord; but it is evident, that much of what he attributes to the sensation of the integuments, as in the prehensile-tailed monkeys for example, is the result of the excito-motory power.

Attached to the grey matter there are two different orders of nervous fibres, the incident and the reflex; whilst, connected with the grey substance of the cerebrum, there are two other orders of fibres, the sensiferous and volition nerves. Now as these latter ordres are subordinate to the exercise of feeling and the will, it is certain that the true spinal cord with its associated nervous fibres is likewise essential to some particular function. The mere fact that the spinal cord directly ministers to muscular motion is, indeed, very generally admitted; the principal point in dispute being as to the precise character of the power it exerts.* So long as the movements of progression were conceived to be entirely voluntary, no other action than volition could be attributed to the spinal cord; but as it has been found that this latter organ does not possess volition, and that it is even very doubtful if the movements of progression, although under the immediate control of the will, are not essentially excited phenomena, the question assumes a new character. It will, however, be more convenient to consider this subject in the last chapter.

9. One of the most important results of this and similar inquiries is, that the peculiar power of the spinal cord, is invariably excited by the application of a physical agent either to the external or internal surfaces of the body; and in this respect, as it has already been stated, it differs essentially from the actions of the brain. The very circum-

* Professor Müller has carefully investigated the influence of the cord over the muscles of the legs. l. c. p. 803.

stance of the spinal power being thus uniformly called into action by the irritation of the incident nerves, affords a strong presumption that the reflex action has an universal existence in the animal kingdom, and in every muscular organ in which the application of a physical agent precedes the muscular action.*

10, 11, 12, 13. The several topics arranged under these heads, are only so many parts of that great controversy touching the relations existing between the nervous and muscular systems, which has so long divided the opinions of physiologists. The subject, however, has been so fully discussed, that it will only be necessary to consider how far the discovery of the reflex power will aid in obviating the uncertainty which still, in some degree, prevails. The extended and valuable researches of Haller tend forcibly to establish the fact, that contractility is the inherent property of the muscular fibre. Indeed, it is now generally admitted, that the muscular and nervous systems are each endowed with independent and peculiar properties; and the only relation existing between them is, that the stimulus by which the power of the latter is called into action is generally, if not uniformly, transmitted through the former.

With respect to pure voluntary motion, it is evident that it may be, and constantly is exercised without any reference to sensation; but inasmuch as the instinctive and involuntary actions, as they are termed, result, perhaps, in every instance, from antecedent impressions made on certain nerves, this agency of the nervous system is assumed as being necessarily accompanied by sensibility, under some form or other. It is not, indeed, supposed that sensation attended with consciousness, which is in reality

* See the observations in the chapter on the great sympathetic nerve.

the only kind of sensation possessed by animals, is necessary to this species of contractility; but, then, it is very generally thought that what is called organic sensibility, is essential to the contraction of the muscular fibre. The discovery of the reflex function will enable the physiologist to reconcile these conflicting opinions, and to perceive that although it is probable in every instance of instinctive and involuntary motion, an impression must be made on some part of the nervous system before contraction can take place, yet that this impression is not necessarily attended with sensation. So many instances have been adduced, in which motions were excited in parts deprived of all feeling, that it is not necessary to enlarge further upon this topic.

It is proper, in conclusion, to state, that the highly important researches of Dr. Hall and Professor Müller, but especially those of the former, have removed one of the greatest obstacles which have opposed the successful investigation of the contractile property, not only of animal but likewise of vegetable bodies. By showing what is the true nature of the excited actions, and by demonstrating their total independence of sensation, these admirable physiologists have dispelled all the vague theories as to the existence of two kinds of sensibility, the animal, and the organic. I believe it will be ultimately established, that every species of animal motion, not voluntary or resulting merely from elasticity, is excited; and, that it is probable, although from our imperfect knowledge of vegetable organization, this, at present, is merely a surmise, that the contraction required for the nourishment and support of plants is the result of an excited action, effected by a structure analogous in its office, though differing in its physical characters, to the true spinal (and, I believe, sympathetic) system of the animal kingdom. Whether this hypothesis be true or not, a grand step is gained in

vegetable physiology, when, by proving that motion may take place altogether without sensation, the necessity of attributing to plants a degree of sensibility, which, however insignificant, must, if it existed at all, have been in character identical with that enjoyed by animals is entirely and satisfactorily obviated.

CHAPTER VI.

THEORY OF THE FUNCTIONS OF THE SYMPATHETIC NERVE.

Dr. Hall thinks that the ganglions of the great sympathetic, and of the cranio-spinal nerves, constitute that part of the nervous system which ministers immediately to the nutrition of the internal and external parts of the body. Without venturing to offer any decisive opinion upon this difficult question, I am desirous of explaining my views of the character of the part of the ganglionic system, appertaining to the great sympathetic.

It is, I believe, susceptible of proof, that the ganglions of this system are the source of an independent power, and that they do not, as Dr. Wilson Philip, and so many other physiologists suppose, derive their energy from the brain and spinal cord; a theory, is in the first place opposed to the fact that the sympathetic exists in those instances of monstrosity, in which both the encephalon and spinal cord are deficient; and in which there is, notwithstanding, every reason to believe that the agency of the ganglions* is essential to the functions of the fœtus, and especially to the circulation.

* These remarks do not apply to the spinal ganglia.

Dr. Fletcher, who advocated a theory respecting the ganglia, which is, apparently, erroneous, has, however, collected many interesting circumstances to prove the paramount importance of these organs in support of the fœtal life. Thus we learn, that although the rudiments of the spinal cord and brain are among the first parts visible, yet, that the ganglions speedily acquire a greater degree of development, and are relatively larger in the fœtus than after birth, so that whilst the cerebro-spinal system is still obscure, the sympathetic and its ganglions are very distinct in the embryo.* It is further remarked, that the first portion of this system which becomes obvious, is the cardiac ganglion. As regards those cases of monsters, in which it is said that no trace of a nervous system of any kind could be discovered, it is probable, as Dr. Fletcher remarks, that attention was particularly directed to the existence of the cerebro-spinal, rather than of the sympathetic system, and that the latter might in an imperfect state have been present, although not detected.

Not only is the theory which derives the power of the ganglions from the brain and spinal cord thus inconsistent with what is seen in the fœtus, but it is decidedly opposed to the great laws which govern the operations of organized bodies. Such a doctrine is allied with that according to which the grey is essential to the formation of the fibrous matter; or to the hypothesis which renders the spleen merely subordinate to the action of the stomach. It is much more in accordance with the laws of the animal economy, to conclude that the ganglions are the independent seat of a power, which is subordinate to the actions of those organs to which the sympathetic furnishes nervous branches.

* Ruds. of Phy. part 2, p. 80.

Various physiologists, from the time of Winslow and Johnstone, down to the present day, have, indeed, advocated the opinion that the ganglions are bodies which generate a peculiar power, — that they are, as it has been said, little brains. This doctrine is, I believe, fundamentally correct; but, as it is encumbered with the hypothesis that the ganglions have the property within themselves of spontaneously originating action, which is equivalent to attributing to these organs an intelligent principle, it has never been established as a physiological truth. Notwithstanding the idea of an intelligent agency has been rejected, it is still very generally supposed that the ganglions bestow on the heart, blood vessels, &c. a degree of sensation, which is essential to their action, and hence have arisen many of those erroneous opinions respecting organic sensibility.

The ganglions of this system present, I believe, a structure which is, with one most important exception, identical with that of the spinal cord, when it is regarded in a collective form; that is to say, as consisting of an excito-motory and a cerebral portion. That these bodies present a great difference in their physical appearance, when contrasted together, is true; but this is, doubtless, owing to the totally different circumstances in which they are placed; for, whilst the cord is most carefully protected from all external violence, by the strong bones of the spine, the theca vertebralis, and other membranes, the ganglions lie external to the vertebral column, with no special covering of bone. In order to give the necessary protection, they are, consequently, invested in a dense ligamentous texture, which not only covers their exterior, but likewise penetrates internally, and thus gives to the entire organ great hardness, so as to render it difficult to detect the real structure.

We find in the ganglions:—

1. Grey matter.

2. Longitudinal and transverse commissural fibres, *ex. gr.* those joining the ganglions, in a longitudinal direction, forming the trunk of the nerve, as it is called; and those joining the ganglions, on the opposite sides of the body, as in the abdomen.

3. Fibres joining the sentient nerves, *ex. gr.*, those going to the nasal branch of the trifacial and posterior roots of the spinal nerves.

4. Fibres joining the motor nerves, as those going to the third and anterior roots of the spinal nerves.

5. Proper fibres.

The great distinction between the spinal cord and ganglions is, that, whilst the cerebral fibres of the former organ transmit impressions which excite sensation and the influence of the will, the cerebral fibres of the sympathetic, only convey impressions which excite pain, as in morbid states of the intestine, and the influence of the passions.

In his work on the Nervous System, Mr. Clark has brought forward a theory, according to which, the ganglia are supposed "to stand in the relation of *axes* or *centres* to their *ultimate* filaments, which form the conducting and reflecting media, between them and the muscular fibres they supply."* Before I was acquainted with Mr. Clark's theory, it had occurred to me that the ganglions of the sympathetic form a part, though to a certain degree an isolated one, of the excito-motory system; and I was led to form this supposition, for the following reasons. In the first place, from the views I had adopted of the grey matter being the sole source of

* The Practical Anat. and Elementary Phy. of the Nervous Sys., 1836, p. 111.

power, it seemed a necessary consequence that these bodies, containing as they do so large a proportion of that substance, must constitute an independent seat of nervous energy; and, with the aid of the reflex principle, it was easy to understand that this power might be excited by the impression of physical agents on the extremities of the sympathetic; and, in this manner, the great objection to the opinion of Winslow, that the ganglions possessed an intelligent agency, might be obviated. Secondly, the existence of the great sympathetic in all its integrity, in cases of deficiency of the cerebro-spinal axis, affords in itself a strong presumption that it forms a peculiar and independent division of the nervous system; in fact, such an induction is equally well founded with the opinion, now universally received, that the spinal cord, as it is seen, for instance, in the anencephalous infant, is an organ, perfect in itself, and independent of the brain. Thirdly, this view is further supported, by the very early appearance of the sympathetic ganglions in the embryo; and by their superior development, when contrasted with the cerebro-spinal system, in the fœtus and young child; or at those exact periods, in which the organs to which their nerves are distributed (those, namely of nutrition), are so remarkable, for the activity of their functions. Lastly, in considering the character of the excito-motory phenomena, — and especially the remarkable fact, that those actions are, invariably, the result of the application of a physical agent to the surfaces of the body, — it was impossible not to be struck with the circumstance, that the contraction of all those organs to which the sympathetic is distributed, with the questionable exception of the kidneys, is incessantly being influenced by physical agents: that of the heart and blood-vessels, by the blood; of the intestinal canal, by the food; of the secreting

canals, of the salivary glands, the pancreas, and the liver, also by the food, through the medium of their relations with the alimentary canal; of the testicle, in coitu; and of the uterus, by the fœtus. There is, in all this, so close an approximation to the mode in which the incident nerves of the spinal cord are excited, that it is difficult not to conclude that the nervous agency in the two cases is identical.

We find then, that, in all the most essential respects; in the possession of grey matter; in the development being regulated, by the degree of activity in the organs with which this system is connected; and in the mode in which its action is excited, there is a most striking correspondence with the true spinal system. But, if it be true that the sympathetic is a part of the excito-motory system, we ought to discover the incident and reflex nerves, by which its action is excited.

It has been above-stated, that the sympathetic, besides the commissural fibres and those by which it is connected with the cerebro-spinal system, possesses a peculiar set of filaments; these latter constitute, I believe, a true excito-motory system of nerves.

In describing the incident and reflex nerves of the spinal cord, I took occasion to remark, that it is no more possible to demonstrate their separate existence in the trunks of the nerves, than that of the sentient and motor fibres; now, it is the same with the cardiac and other branches of the sympathetic, in which it is impracticable to distinguish, by their physical characters, the different component fibres. It is known that these nerves contain, at least, two distinct orders of threads, by which impressions are carried to and from the brain; and the mere fact that no other fibres, proper to the ganglionic nerves, have hitherto been detected, is no proof of their non-existence.

It must, however, be confessed, that, owing to the particular disposition of the component parts of the great sympathetic, it is extremely difficult, and perhaps, generally speaking, impossible, to demonstrate the separate existence of such a system. It is not, for example, feasible, in this instance, to adopt the mode by which the four orders of fibres have been detected, in the spinal nerves; for, when the fibrils of the sympathetic reach the ganglions, the intricacy is such that no one has, hitherto, succeeded in discovering their exact arrangement. There is, indeed, one particular division of the great sympathetic, the submaxillary ganglion and its branches, which seems to furnish a clue; resulting from the circumstance of its being, in a certain degree, isolated; and especially because the organ which receives the impression, the tongue, and those organs which contract, in consequence of that impression (the tubes of the salivary glands), are separated from each other. In order to obtain a just conception of the true relations of these and other ganglionic nerves, it will be necessary to enter into some anatomical details.

The submaxillary ganglion is neither placed on the chorda tympani, as Cloquet supposed; nor is it formed, as Cruveilhier asserts, by the most inferior fibrils of the lingual nerve. Professor Arnold, who has represented this nerve, has given the most accurate account of its connexions, which has yet been published; he has not, however, noticed all the branches of this little system, which may be received as the type of the great sympathetic.* In reflecting upon this subject, I was induced to conclude, that, besides the branches which are furnished

* Icones Nervor. Capitis Tab. 7. By referring to this plate, the reader will be enabled, more readily, to comprehend the theory contained in the text.

to the submaxillary gland, there must be others supplying also the sublingual gland; and, therefore, to determine this point, my colleague, Mr. Walker, dissected this ganglion, and the following is the result of a careful dissection. Many more branches than are figured by M. Arnold, are given off from the lower border of the ganglion, and enter the submaxillary gland; two or three others pass upwards, behind the gustatory nerve, then above and parallel to the Whartonian duct, into the substance of the sublingual gland; the latter twigs are not noticed by Arnold, Hildebrandt, Cruveilhier, Swan, nor, I believe, by any other anatomist. The branches, then, of the submaxillary ganglion, are,—1, to the great sympathetic; 2, to the chorda tympani; 3, from its upper and outer border twigs, to the gustatory nerve; 4, a second order of twigs, from the upper and inner edge to the gustatory nerve; 5, fibres to the submaxillary gland; 6, filaments to the sublingual gland. Notwithstanding the extraordinary number of different branches, each class of them is, doubtless, provided for a special purpose; and, without asserting any thing positively, it may be suggested that the fibrils of the first order are commissural branches, like those uniting the other ganglions together; that the second transmit the influence of mental emotions, which are capable of affecting all the organs supplied by the sympathetic, the effect, in this instance, being confined to causing a flow of saliva, on seeing or even thinking of food; that the third convey impressions to the brain, as in inflammation of the salivary glands, exciting pain; that the fourth are incident branches, arising from the surface of the tongue; that the fifth and sixth are reflex branches, going to the two glands. The flow of saliva, during mastication, is generally supposed to result from the motions of the jaw; or from a kind of

continuous sympathy, caused by the mucous membrane of the mouth entering into these glands; but it is much more in accordance with the manner in which muscular contraction in general is determined, to attribute this phenomenon to the impression made on the nerves of the tongue, by the food exciting, through the medium of the ganglion, the contractility of the secreting canals; a supposition which is rendered the more probable, by the well-known fact that certain substances act as sialogogues (tobacco, for example), by the irritation which they cause on the tongue.

In the case of the saliva, there is an instance of a secretion flowing, in consequence of the contact of a physical agent, food, with what appear to be incident nerves. That this is the correct view of what takes place, is powerfully corroborated, by the manner in which the flow of the gastric juice is regulated. Previous to the important researches of Dr. Beaumont, it was supposed that this fluid was constantly being poured into the stomach; but this acute observer has discovered that in this, and doubtless in every similar process, there is no such useless expenditure; the true gastric juice only flowing during the process of digestion. It is impossible to adduce any more beautiful illustration than this, of the perfection of the laws by which the operations of the animal economy are regulated; for it is perceived that the pouring forth of the solvent fluid, is made to depend on the irritation caused by that identical substance, the food, the presence of which, in the stomach, requires that of the gastric juice. That the aliment, in making this impression, acts merely as a physical agent, is shown by the fact that any other mechanical irritation is equally efficacious; thus, Dr. Beaumont ascertained that the proper secretion of the stomach flowed, whenever the

inner surface was touched by the bulb of a thermometer.

The fluid which the stomach contains, in the intervals of digestion, is the common mucus secreted by all mucous membranes.*

If it be admitted that any nervous power at all is required, to effect those processes which take place in the fœtus—circulation, secretion, and nutrition—and it is almost impossible to arrive at any other conclusion, it is certain that it is the agency of the great sympathetic, and not of the cerebro-spinal system, which is necessary; for it is known that the development of the fœtus is, in other respects, perfected in those cases of monstrosity in which both the brain and spinal cord are deficient. It is then highly probable that the ganglionic system is in action during the fœtal life; and it is almost certain that this action is excited or dependent on the reflex principle. The heart may be selected for the sake of illustration; the blood reaching the cavities of that organ makes an impression upon the incident branches of the cardiac nerves; this impression excites the power of the cardiac ganglion, the influence of which being transmitted by the reflex cardiac twigs, causes the muscular substance to contract.†

At the present time, when the anatomy of the great sympathetic is so very imperfectly known, it is impossible to affirm any thing with certainty concerning its functions. It may, however, be remarked that the interesting phenomena, connected with the flow of the saliva, of the gastric

* Expts. and Obs. on the Gastric Juice, and the Physiology of Digestion. Boston, 1834.

† If the cardiac nerves and ganglion are essential to the heart's action, and that they are so, will, I feel confident, be ultimately established, their action must be excited; or otherwise we must allow that the ganglions can spontaneously stimulate the muscular fibre, or, in other words, that they are intelligent agents.

juice, and the bile, seem to indicate the existence of a general law regulating the contraction of those structures which are supplied by the great sympathetic; in virtue of which, the involuntary organs of the circulation and secretion never contract but upon the application of a mechanical stimulus to the extremities of the nervous filaments.

Many considerations, the principal of which have been stated, induce me to suppose:—

1. That the great sympathetic consists of several distinct nervous systems, each of which is endowed with an independent power.

2. That every ganglion is provided with incident and reflex fibres which are necessary to the exercise of its peculiar power.

3. That the contraction of all the organs which are in a more especial manner supplied by the great sympathetic, is in every instance excited through the agency of the incident and reflex nerves.

4. That the power of the ganglions is invariably excited by the application of a physical agent to the incident nerves, distributed to the internal surface of the heart, blood vessels, intestines, and secreting canals of all glandular organs.

5. That the sympathetic ganglions are connected together by commissural fibres; and to the cerebrum by branches which join the sentient and motor cranio-spinal nerves, by which impressions are reciprocally transmitted between the brain and the organs supplied by the sympathetic.

CHAPTER VII.

THEORY OF MUSCULAR ACTION.

THE phenomena displayed in the muscular organs of the body, are so intimately allied with the properties of the nervous system, that until the latter have been determined with some degree of exactness, it is impossible to ascertain, in an accurate manner, the real character of the former. The first great step in the path of improvement, was made by Haller, when, completing what was begun by Glisson, he succeeded in proving the distinctness of the muscular property, contractility, and of the nervous power, sensibility. Although physiology is deeply indebted to this illustrious man, for this grand discovery, there cannot be a doubt that his adoption of the vague expression, irritability, has led to the most injurious results; and I perfectly coincide with Dr. Bostock, who has so ably treated this question, that the interests of science would be promoted by the substitution of the much more definite word, contractility.

Since the time of Haller, it appears to me that no discovery relative to the respective endowments of the muscular and nervous systems, can compete with that of the reflex power of the spinal cord, and of the distinction between that property and sensation. But so much having

already been said as to the views of Dr. Hall and Professor Müller, it is only necessary to remark in this place, that neither of these writers have carried the great principle they have discovered, to what appears to be its full and legitimate extent. Dr. Hall states, that "physiologists have hitherto enumerated only three sources or principles of muscular action, volition, the motive influence of respiration, and irritability. There is, however, a fourth source of muscular motion, distinct from any of these, though not hitherto distinguished, to which I have ventured to give the designation of the *reflex function of the spinal marrow.*"* Dr. Hall thinks that the heart and other muscles contract upon the principle of excited irritability, and, consequently, that their contraction does not depend upon the reflex function. Professor Müller, who in so many other respects limits the extent of the excito-motory phenomena, agrees in the opinion that the heart contracts in consequence of a stimulus acting directly on its substance; and he further remarks, that "it is necessary to distinguish between reflected motions and the involuntary non-reflected motions."†

The inquiries in which I have been for some time engaged, induced me to believe that muscular contraction‡ is only excited by three causes:—the first consisting of volition, the second of the reflex power possessed by the spinal cord and the ganglions of the great sympathetic; and the third by the passions, fear, joy, &c. Contraction thus excited, is, I believe, the

* Memoirs, p. 30. † Hand. der Phy. p. 698.

‡ It is proper to state, that under this term I include the contraction exercised by every organ, whether a muscle of the extremities, the heart, the muscular coat of the intestines, the fibrous tunics of the blood-vessels, or of the secreting canals in glands, which produces perceptible motion; in fact, every kind of contraction which is not attributable to elasticity.

source of every kind of perceptible motion which is displayed by animal bodies; the influence of the will being the more restricted, and extending only over the muscles supplied by the cerebro-spinal axis; whilst the control of the reflex power and of the passions, is exerted over every muscular organ in the body. It is not my object to discuss all the various phenomena connected with this comprehensive branch of physioloy; but merely to consider how far they may be elucidated by the application of the excito-motory principle. It will facilitate this inquiry, if it be divided into three parts, by which means, what are commonly called the voluntary, the instinctive, and the involuntary motions, may be noticed separately from each other.

1. *Of voluntary motion.*—The investigations respecting the extent of the reflex action, have sufficiently proved that many of those motions which had heretofore been regarded as voluntary, are in reality excited; among these may be mentioned the closure of the eye by the orbicularis palpebrarum, upon the eyelash being touched; the contraction of the lips in the new-born infant, when touched by the nipple; the closure of the glottis when irritated. Other instances might be readily adduced to prove that the muscles reputed to be voluntary in their character, may have their actions called forth independently of volition; those of the arms and shoulders in sneezing, or in drawing a deep breath; of the hand, when the finger touches any very hot substance; those, again, of the leg, when the foot is irritated after the division of the spinal cord. Without further multiplying these examples, it may be stated, that there is probably not a single muscle of the voluntary class, that may not have its action excited independently of volition.

It is justly observed by the writer of a critique on Dr.

Hall's published Lectures, that "if we make a system of excito-motory nerves, we must include in that system all the nerves of common sensation, and probably all those of voluntary motion."* Such a system, Dr. Hall contends, does exist; but he has not succeeded in proving the conclusion to which he was conducted, as a consequence of his physiological inductions. I have in another place laid before the reader the reasons which have satisfied me that in every nerve of the cranio-spinal system, excepting perhaps the olfactory, there are fibres which, with the true spinal cord as their central axis, constitute the excito-motory system; and that there are besides these, the fibres previously known, the true cerebral. Thus, then, as far as the anatomy is concerned, the conditions which both the advocates and the opponents contend must be fulfilled, provided the theory of the reflex function be true, are realised.

These observations were required, in order to show that every muscle called voluntary may have its contraction called into action either by the will, operating through the cerebral or proper volition fibres of the motor nerves; or by the power of the true spinal cord, acting through the reflex fibres of the motor nerves, which power is itself excited in the first instance by a physical agent, producing an effect on the incident fibres.

But it is a task of the greatest difficulty to separate the actions which are purely voluntary from those that are purely excited; it is still more so to distinguish these two kinds of motions from each other, when they occur, as they often do, in conjunction; and all this becomes much more complicated in the lower animals. We are able in ourselves to decide, that many motions

* British and Foreign Medical Review, January 1837, p. 37.

are altogether voluntary, because we are perfectly conscious that they are the direct result of our will; by far the greater number of the movements of the upper extremities, for example, are clearly of this character. Again, there are many actions occurring at times in the muscles, called voluntary, which, we are aware, are not the result of volition, as the closure of the glottis, when that part is irritated by a noxious gas.

Those motions in which volition and the reflex power act more or less in concert, are doubtless the most intricate, and at the same time the most interesting to analyze. Two examples of these movements, as I believe them to be, may be selected,—deglutition and locomotion.

Before the observations of Magendie,* no physiologist, doubted that swallowing, as far at least as thefauces were concerned, was altogether a voluntary action; no one at the present time doubts, that the essential part of this process is involuntary, or, to speak more correctly, excited. The cause of this error, since the elucidation afforded by Dr. Hall, is apparent; the first stage of the function, that of placing the food upon the tongue, is, when we are at all conscious of the process, for it has been shown that it may occur during sleep, or in a state of complete insensibility, the result of the will; in all the other stages, although they may be attended with sensation, the motions are excited.

It appears that a case nearly, but not altogether analogous, is furnished by the function of locomotion. No one at this time doubts, that all the complicated muscular actions which are necessary for progression, are perfectly voluntary; and yet, if the process be scrutinised, not merely as it occurs in man, in whom, owing to the

* See p. 84.

immense predominance of the intellectual phenomena, the mere bodily faculties are so much obscured, but in the whole series of the animal kingdom, it will become apparent that, besides the will, there is some other power in operation.

In insects, which in this respect may be received as the type of the immense division of the articulata, we see the extraordinary phenomena of an animal walking and flying without its brain, consequently, without sensation and volition; but these actions never take place spontaneously, for if they did, they would demonstrate the existence of a power of willing. In every instance, the motions of the limbs are either the result of that intense stimulus which is communicated to the cord by cutting it across, or of mechanical irritation. (See fig. 4.)

In the frog, the rabbit, kitten, &c., after all feeling and volition are lost, the limbs are moved when the skin is touched. This motion has either been considered as the withdrawal of the part from a painful impression,* or it has remained altogether unexplained, even by those who have investigated the reflex action. It has been shown that the retraction of the leg in an animal thus treated, is partly attributable to that preservative power, in virtue of which every part of the body possesses the means of withdrawing itself, not simply from a painful, but from an injurious impression.† But although this cause is sufficient to account for the simple retraction of the foot when it is pinched or burnt, it offers no solution of those remarkable and combined motions which have been described;‡ nor of the fact, that the part of the limb which, in progression, comes in contact with the ground, is so much more excitable than any other portion of the integument.§

* See p. 7.
† See p. 58.
‡ See Exp. 1. P.
§ See Exp. 7, et alibi.

The foot of the rabbit is not only drawn away from the irritation, but the whole limb, occasionally even both legs are forcibly thrown backwards, with all the complicated motions that occur when the creature runs. In the frog, if the cord be divided sufficiently high, both hind legs often strike out when one is touched, not in the manner of the rabbit, but with the very action that occurs in swimming. The chicken, in the experiment of Flourens, when deprived of all volition, flew when thrown into the air. Lastly, in the human body, the legs may be excited to motion, when all voluntary power is destroyed, by tickling the sole of the foot.

It is thus proved, beyoned the possibility of a doubt, that motions similar to those performed in the progression of the animal, may be excited by touching the skin, when volition and sensation are destroyed. The question naturally suggests itself,—*what is the object of this power?* It is certain that a property so constant in its operation, and so definite in its results, is not bestowed without a reference to some special purpose. The circumstances under which it occurs, in a part deprived of sensation and volition; the manner in which it is excited, by a physical agent; the law by which it is regulated, which shows that it is more developed in some particular parts than in others; all these facts so strongly resemble what takes place in organs where it is known, as in those of deglutition, that the excited actions are unquestionably functional, that it is scarcely possible to doubt that in the legs the motions produced are also functional, or that they have a reference to locomotion.

When, in walking, the foot strikes the ground, if we pay any attention at all to what takes place, we are only conscious of the sensation which is excited; the motions of the limb are overlooked, or it is concluded that they are

purely voluntary. And so it is in the case of deglutition; a sensation is produced by the contact of the food, and, until lately, it was thought that the motions consequent upon that contact, were voluntary. It is then, I think, most probable, that in progression, an impression is made on the incident nerves of the foot, by which the reflex power of the spinal cord is excited to action, and the combined and required motions are produced. This explanation does not in any degree exclude the idea of due and proper control being exerted over the limbs in walking, flying, swimming, &c.; inasmuch as there are proper nerves, the cerebral, going to every voluntary muscle, by which the animal can at will direct, quicken, or give increased vigour to the motions; it is even probable that a special apparatus provided, for the purpose of enabling the animal altogether to prevent or stop the excited actions. It is also evident, that these excited actions of the legs must be much more perfect and influential in the lower than in the higher animals, exactly in proportion to the relative development of the spinal cord and brain; so that whilst in some of the lowest tribes progression is almost entirely a spinal action, in the mammalia, and, above all in man, the central influence is greatly exerted.

The muscles called voluntary are then probably all susceptible, under different circumstances, and in varying degrees, of being stimulated by the brain, through the medium of volition, and by the spinal cord, through the means of the reflex power.

It was proved by Flourens, that the spinal cord is capable of so co-ordinating the muscular contractions, as to produce combined motions of the joints, such as flexion, extension, &c.; but he supposed the cerebellum was the regulator of these combined motions, and that in this manner that organ was necessary to effect walking,

flying, &c. It appears, however, that the cord is itself efficient to produce the motions of progression, although, doubtless, all power of controlling, directing, quickening, retarding or stopping these actions is a purely cerebral function.

*Instinctive motion.** — This term is usually applied to such actions as the sucking performed by young infants, deglutition, breathing, &c. Dr. Hall has so very satisfactorily elucidated these phenomena, and they have been so minutely considered in the former part of this treatise, that it is unnecessary to dwell on them in this place.

Involuntary Motions. The real character of the contraction of the heart, intestine, secreting canals, &c. is, as yet, unknown. The heart's action is very commonly supposed to result from the immediate contact of the blood, with its muscular substance; a similar account is also given of the peristaltic motion; whilst as far as the flow of saliva into the mouth, of the gastric juice into the stomach, and the bile into the intestine, it is vaguely attributed to what is called, continuous sympathy. This question is intimately associated with that relative to the endowments of the great sympathetic.

The theory by which the contraction of the involuntary muscles is referred to immediate contact with their fibres, is, when carefully considered, very unsatisfactory. It may, in the first place, be observed, that in no organ does actual contact take place; there is always a membrane interposed between the fleshy fibres and the contents of the organ. But, even allowing that where the muscular planes, as in the intestine, are so thin as to allow the food to approach

* It is necessary to distinguish between instinctive motions, such as those mentioned in the text, and the instinctive principle which impels animals to perform certain acts, such as the construction of nests by birds; the former are spinal, the latter, I believe, cerebral phenomena.

sufficiently near to make the requisite impression, how can this be supposed to happen in the left ventricle of the heart, where there is such great thickness of the parietes? The only manner in which it can be imagined that the fibres towards the outer surface, or pericardium, are capable of being stimulated, is by an impression transmitted through the cardiac nerves; but such an explanation belongs to another and different hypothesis. This subject may be elucidated by considering the action of two structures, both of which are employed in the same office, that of propelling the food along the alimentary canal. In the fauces, it is not supposed that the numerous muscles employed in that action are made to contract by the actual contact of the food; indeed, the relative situation of the parts implicated, some of the muscles being placed so remotely in the neck, renders such contact physically impossible. It is, indeed, now known that the process of deglutition is excited; but then it is supposed that when the food descends rather lower, and reaches the pharynx, œsophagus,* and intestine, that a new principle of muscular action is called into operation, and that contraction is effected, not through the medium of the nerves, but by direct contact with the muscular substance. This idea has doubtless originated from the membranous form which the muscular structure assumes in the œsophagus and intestine, and partly from the difficulty of unravelling the nerves of the abdomen. It is not, however, probable, that parts so very analogous to each other, as the œsophagus and fauces, and which are supplied by the same nerves, should have their action excited in two different modes.

* Professor Müller has very justly questioned the correctness of Dr. Hall's original opinion that the action of the œsophagus is caused by immediate contact. Dr. Hall has since modified his views on this point.

With respect to what is called sympathy, it may be observed in general, that it is a word to which the most vague meaning is attached, but which is nevertheless very commonly employed, as if it explained the cause of some of the most important phenomena of the economy, whilst it is nothing but a term by which those phenomena are designated. The continuous sympathy which is said to be the cause of the saliva flowing into the mouth when this cavity contains food, is but an expression by which is signified the effect produced in the salivary glands, by the impression made on certain nerves of the mucous membrane of the tongue. The same error which has prevailed on so many other subjects connected with the properties of the nervous system, is particularly exemplified in the present instance; for whilst it is believed that sympathy is but a modification of sensation, it has been proved that this form, or continuous sympathy, is displayed by the flow of the saliva, gastric juice, &c., when all sensation has been destroyed. I have endeavoured in the preceding chapter, to explain the manner in which the impression acts, and how it is that saliva is poured out at the exact moment when it is required.

Such, then, being the unsatisfactory character of the existing opinions respecting the contraction of the involuntary muscles, it is most desirable to endeavour to establish some more reasonable principles. From what has been said in the preceding chapter, it will be perceived that I think all the motions which are called involuntary, are, in reality, excited; that the ganglions of the sympathetic are the seat of an independent power; and, that like the spinal nerves, the ganglionic possess incident and reflex fibres, by which the impressions of the physical agents implicated in these actions are transmitted. In this manner the absurdity of attributing an intelligent

agency to the ganglions is obviated, whilst at the same time a source of power is attributed to these organs, which, from analogy and other sufficient reasons, it must be presumed they possess.

In concluding these observations on the properties of the spinal cord, it may be remarked, that taken in conjunction with other researches of a similar character, they appear to indicate the existence of a peculiar, and, until the discoveries of Hall and Müller, an unknown source of muscular action, essentially independent of sensation, and entirely distinct from the motions produced by volition and passion.

The discovery of the reflex power, even in its present imperfect state, furnishes the means of reconciling and explaining most of the difficulties and anomalies presented by the phenomena of contractility in the animal and vegetable kingdoms; and there can be little doubt when this principle has been carried out to the extent of which it is susceptible, that it will enable the physiologist to penetrate into all those mysteries connected with the movements of organised bodies, which have, hitherto, baffled his researches. The great question at present requiring solution, is the real character of that contractile power possessed by plants, and by the numerous tribes of beings placed at the bottom of the animal scale. The received opinion that the motions displayed in these instances, are necessarily allied with some kind of sensibility, is only one of the innumerable errors which have flowed from the same source; the doctrine, namely, which inculcates, that contraction is necessarily connected with sensation. Dr. Hall has strongly insisted upon the entire fallacy of this

hypothesis; and the great end of the present treatise is to demonstrate the fact, that sensibility and contractility have no necessary connexion, and to show the real relations which exist between these, the two great characteristics of animal existence.

It is probable that all those animals, which are permanently fixed in their habitation, possess no sensation; and that with respect even to those which enjoy locomotion, by far the greatest number of the movements they evince, are excited, and not voluntary actions. In the former instance, the endowment of feeling bestowed on a being which has no power of escaping from painful impressions, would be an anomaly which has no parallel in the beneficent scheme of creation. But it may be asked how we are to account for the free motions which so many of these classes display in parts of their body, especially in the cilia,* and even the kind of choice which they often seem to evince in their actions. The extraordinary movements occurring even in the highest animals, when all sensation and volition are destroyed, is a sufficient reply to the former objection; and as regards the latter difficulty, we know so little of the influence on animal textures of the most subtle, but at the same time the most potent agents of nature, light, heat, and electricity, that no argument in favour of the existence of sensation can be deduced from the circumstance that the sea enemone expands in the light of the sun, and that the escholtzia closes in the shade of the evening. Even it is quite possible to conceive how the arms, mouth, and stomach of the

* That the motions of the cilia, incessant and rapid as they often are, do not result from any voluntary action, may be established by the fact that these minute fibrils not only exist in the ova of zoophytes, but even upon the mucous sufaces of the most perfect animals. See the able article, Cilia, by Dr. Sharpey, Cyclopæd. of Anat. and Physiol. Part 6.

polype may seize, swallow, and digest its prey, as in the analogous case of the anencephalous infant, without instinct, sensation, or volition.

The contraction of the vessels which circulate the sap, the phenomena observed in the process of generation, and the free motions seen in the mimosa pudica, may all readily be explained upon the principle of the reflex action; so that the botanist is able to obviate one of the most serious difficulties in vegetable physiology, the presumed necessity of sensibility in plants.

It has been well observed by Dr. Hall, that this great inquiry, is but just begun. It is still surrounded by many difficulties; and, in a much more limited degree, is opposed by what have the semblance of positive contradictions. But it may be affirmed, that no principle of equal importance has in so brief a space unfolded so many and such interesting phenomena, or been encountered by so few real objections.

Much then, both as regards the physiology and the anatomy, remains to be accomplished; and important discoveries will, doubtless, reward those who may be contented to enter upon the path of patient and continued observation.

APPENDIX.

CLASSIFICATION OF THE NERVOUS SYSTEM, ACCORDING TO ITS PHYSIOLOGY.

I. Sources of Power.

Grey matter of — A, Brain; B, True Spinal Cord; C, Ganglions.

II. Conductors.

A. Fibres of the Brain; B, Fibres of the Spinal Cord; C, Fibres of the Nerves.

III. Divisions of the Nervous System.

A. True Cerebral System.

a. Convolutions of the Cerebrum and laminæ of the Cerebellum.

b. Sensiferous Nerves, comprising the true sensiferous fibres of—

1. Olfactory.
2. Optic.
3. Auditory.
4. Gustatory.
5. Nerves of the Skin, viz., Cerebral Fibres of the portio major, of trifacial and of the posterior roots of the Spinal Nerves.
6. Nerves of the Mucous Membrane, viz., Cerebral Fibres of the portio-major, trifacial, glosso-pharyngeal, pnemuogastric.
7. Sentient Fibres of the great Sympathetic, supplying the organs of organic life.

A. True Cerebral System continued.

c. Volition Nerves, consisting of the cerebral fibres of
1. Oculo-motor.
2. Pathetic?
3. Portio Minor of Trificial.
4. Abductor.
5. Portio dura.
6. Glosso-pharyngeal
7. Pneumo-gastric.
8. Accessory?
9. Sublingual.
10. Anterior roots of the Spinal.

B. Excito-motory System.

1. True Spinal System.

a. Grey matter of the true Spinal Cord.

b. Incident Fibres of
1. Optic.
2. Auditory.
3. Portio major of fifth.
4. Glosso-pharyngeal.
5. Pneumo-gastric.
6. The posterior roots of the Spinal.

c. Reflex Fibres of
1. Oculo-motor.
2. Pathetic?
3. Portio Minor of Trifacial.
4. Abductor.
5. Portio dura.
6. Glosso-pharyngeal.
7. Pneumo-gastric.
8. Accessory.
9. Sublingual.
10. Anterior roots of the Spinal.

2. Sympathetic System.

a. Grey substance of the Sympathetic Ganglions.

b. Incident branches of
1. The Ganglions of the trunk of the great Sympathetic.
2. Cavernous?
3. Lenticular?
4. Spheno-palatine.
5. Optic?
6. Submaxillary.
7. Cardiac.
8. Semilunar.

c. Reflex branches of the same Ganglions.

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